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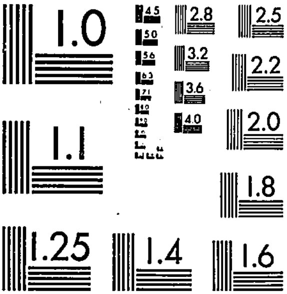

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NOVEMBER 1990

INFORMAL REPORT

EARTHQUAKE STRONG GROUND MOTION ESTIMATES FOR THE IDAHO NATIONAL ENGINEERING LABORATORY FINAL REPORT - SUMMARY VOLUME I

EG&G Idaho

Work performed under DOE Contract No. DE-AC07-76ID01570

EXECUTIVE SUMMARY

In this report, deterministic site-specific strong ground motion estimates in terms of peak horizontal ground acceleration and acceleration response spectra have been determined for the following existing or proposed INEL facilities: NPR, SIS, FPR, ATR, ANL, PBF, NRF, LOFT and RWMC. An earthquake of moment magnitude M 6.9 (surface wave magnitude M_S 7.3) similar to the 1983 Borah Peak earthquake but occurring along the southern segment of the Lemhi Fault near the town of Howe (previously called the Howe fault) is considered as the maximum event for seismic safety analyses. The ground motion estimates are based on a methodology incorporating the Band-Limited-White-Noise (BLWN) ground motion model coupled with random vibration theory (RVT). An equivalent-linear formulation was also used to model the non-linear response of unconsolidated sediments. A finite fault rupture model approach was also evaluated to assess the conservatism of the BLWN-RVT methodology which assumes the earthquake is a point source. A 16-station seismic attenuation and site response survey utilizing three-component portable digital seismographs was also performed for a five-month period. The near-surface crustal attenuation and relative site response have been evaluated based on an analysis of the strong motion accelerograms of the 1983 Borah Peak earthquake recorded at the INEL and seismograms of selected regional earthquakes recorded by the temporary seismic survey. An analysis of the selected regional earthquakes also showed the ratio of peak vertical to peak horizontal accelerations to range from 0.160 to 0.996 with an average ratio of 0.72 for rock sites and 0.45 for soil sites. Geologic profiles based principally on available shallow borehole data and κ estimates from the 1983 earthquake and recorded regional events, have been developed for each site and used in the ground motion estimates. The peak horizontal accelerations for the twelve sites (nine rock sites and three soil sites) at the ground surface for the Howe earthquake range from 0.09 to 0.40 g at distances of 27 to 10 km, respectively. The subsurface geology, specifically the contrasts in shear-wave velocities and Q_S between the

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EARTHQUAKE STRONG GROUND MOTION ESTIMATES FOR THE IDAHO NATIONAL ENGINEERING LABORATORY

FINAL REPORT - SUMMARY
VOLUME I

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basalt layers and the sedimentary interbeds and the absence of a strong shear-wave velocity gradient in the profile has a significant effect on the ground motion estimates. The thicker sedimentary interbeds in the basalt section also appear to significantly attenuate ground motions according to the BLWN-RVT ground motion methodology.

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INTRODUCTION

This final report describes and summarizes the results of an investigation performed by Woodward-Clyde Consultants (WCC) and EG&G Idaho, Inc. (EG&G) to assess the potential strong earthquake ground motions that might be experienced at the Idaho National Engineering Laboratory (INEL). Two factors have motivated this study: (1) the recognition that large earthquakes such as the recent 28 October 1983 moment magnitude (M) 6.9 (surface wave magnitude [M_s] 7.3) Borah Peak earthquake may occur in the future to the north of the INEL; and (2) site-specific strong ground motion parameters for seismic safety analyses have not been developed to date. The approach taken in this study is deterministic rather than probabilistic with the purpose of possibly examining the largest ground motion parameters that could affect the INEL. As such, we have considered a hypothetical earthquake similar to the 1983 Borah Peak earthquake, M 6.9, but occurring along the southern segment of the Lemhi fault as the maximum event for analyses. This fault segment has been recognized as the closest significant potential earthquake source to most of the facilities at the INEL. The selection of the magnitude of the maximum event on this source is based primarily on a desire to use the 1983 Borah Peak earthquake as a model for comparison. It was beyond the scope of this study to evaluate the design earthquake. Recent preliminary empirical estimates, however, suggest the selected magnitude is reasonably conservative, even if rupture were to involve more than one segment along the southern Lemhi fault. Paleoseismic investigations are also currently underway to further evaluate these issues.

We have estimated ground motions at the ground surface for the following nine rock and three soil sites at the INEL (Figure 1):

<u>Rock</u>

- New Production Reactor (NPR) site
- Advanced Test Reactor (ATR)

- Argonne National Laboratory (ANL)
- Fuel Processing Restoration (FPR) Facility
- Power Burst Facility (PBF)
- Naval Reactor Facility (NRF)
- Loss of Fluid Test Reactor (LOFT)
- Radioactive Waste Management Complex (RWMC)
- INEL-1 exploratory borehole

Soil

- Special Isotope Separation (SIS) Site
- Argonne National Laboratory (ANL)
- Loss of Fluid Test Reactor (LOFT)

The majority of critical facilities at the INEL have been constructed on rock and so the ground motion estimates were computed for rock sites with the above exceptions.

The methodology employed in this study has been used recently in seismic safety reanalysis for 57 nuclear power plants in the eastern U.S. and has been presented to, reviewed and accepted by the Nuclear Regulatory Commission (NRC). The strong ground motion parameters determined in this study represent our best estimates based on available data and a state-of-the-science methodology. Due to the uncertainties regarding the characterization of the maximum earthquake and the geologic profiles beneath all the facilities (specifically layer composition and thicknesses and their material properties), these strong motion parameters will probably be refined as more data becomes available. A program of deep drilling could provide more reliable information on the geology beneath the eastern Snake River Plain (ESRP) and thus reduce the uncertainties of these estimates. The results of this study have been incorporated into a strong ground motion evaluation for the NPR site which is being performed by Lawrence Livermore National Laboratory.

Because the site-specific ground motion parameters in this study are highly dependent upon the assumed geologic profiles beneath each of the sites, the computed acceleration response spectra should not be used directly for seismic design, but rather as a basis for developing new design criteria or comparing against existing criteria.

The results of this study are presented in three volumes: Volume I is the Summary Report, which contains a summary of the study and the site-specific ground motion estimates for each facility; Volume II includes detailed descriptions of the methodology, some of the input parameters and additional results; and Volume III, the Appendices, contains the geologic profiles, recorded time histories of the regional earthquakes and the processed data.

Scope of Work

The specific primary objectives of this study are:

1) provide site-specific estimates of peak horizontal ground acceleration and acceleration response spectra at the ground surface for selected sites located on soil or bedrock at the INEL;

2) develop a peak acceleration-attenuation relationship for earthquakes in the magnitude range 5 1/2 to 7 1/2 that is specific to the INEL;

3) provide technical support and portable digital seismographs for a site response and crustal attenuation survey of selected sites in and around the INEL; and

4) process and analyze the data recorded by the survey to evaluate local site response, seismic attenuation, and the ratios of vertical to horizontal peak ground accelerations.

The strong ground motion parameters for specific sites have been estimated based on the Band-Limited-White-Noise (BLWN) ground motion model combined with random vibration theory (RVT). Additionally, ground motions have been computed for a single site based on a finite fault rupture model to assess the conservatism of the BLWN-RVT methodology which is being employed at short source-to-site distances and assumes a point source representation for the earthquake. The analysis of data recorded by the seismic survey resulted in estimates of kappa (κ), the near-surface attenuation factor, and relative site response which were used as input in the BLWN-RVT calculations. Geologic profiles have been developed for each site based on available shallow borehole data and modeling comparisons with the 1983 earthquake and the regional events. These data have been incorporated into the site-specific ground motion estimates.

This study was performed within the guidelines of the EG&G Idaho, Inc. Quality Assurance (QA) Program. QA work plans and procedures for the operation of the temporary network and instrument calibration and verification and validation documentation for the various computer programs used in the data processing and analysis are on file with EG&G Idaho, Inc.

Previous Studies

The first studies to evaluate potential seismic hazards at the INEL were performed by the U.S. Geological Survey from 1967 to 1969 (Malde et al., 1971). At the request of the U.S. Atomic Energy Commission, geologic studies including trenching along the Arco scarp of the Lost River fault and the Howe scarp of the Lemhi fault were performed. Malde et al. (1971) concluded that "large earthquakes related to renewed faulting along these scarps might recur at any time in the future".

Based on empirical relationships between (1) surface fault rupture length versus earthquake magnitude, and (2) magnitude, distance to the source and peak ground acceleration, WCC (1975) considered the Howe scarp fault to be the most significant earthquake source to the Loss of Fluid Test (LOFT) Reactor, capable of producing a magnitude 6-3/4 earthquake. Such relationships were, however, based on data of earthquakes occurring outside the intermountain U.S. A peak horizontal bedrock acceleration of 0.34 g was predicted at a distance of 13.6 km for this event (WCC, 1975).

In a study for the New Waste Calcining Facility (NWCF), Allied Chemical Corporation (1975) predicted a peak horizontal bedrock acceleration of 0.33 g (0.22 g vertical) at the Chemical Processing Plant (CPP) assuming the possible occurrence of a Richter magnitude M_L 7-3/4 earthquake on either the Arco Pass or Howe scarp faults (actually the southern segments of the Lost River Range and Lemhi faults, respectively). Assuming the WCC (1975) design earthquake of M_L 6-3/4 on the Howe scarp fault, Agbabian Associates (1977) estimated a peak horizontal acceleration of 0.37 g (rounded up to 0.40 g) at the ground surface for the LOFT reactor. Similarly for the NWCF, Agbabian Associates (1977) estimated a 0.30 g peak horizontal acceleration at the ground surface at a distance of 24 km. These values were estimated from the mean plus 50% curve of a Mercalli intensity-attenuation relationship developed from five intermountain earthquakes including the 1959 Hebgen Lake earthquake.

Agbabian Associates (1977) also reviewed the evidence for two factors that had been speculated upon as possibly diminishing the levels of earthquake ground motions within the Snake River Plain: (1) possible "decoupling" of the Plain by perimeter faulting; and (2) possible attenuation due to the interbedded alluvial layers within the basalts. It was concluded that there was no evidence to date to indicate the existence of either process. The latter was considered unlikely because the seismic waves would not be affected by the interbeds due to the thinness of the interbeds in comparison with the wavelengths.

Agbabian Associates (1977) also performed a probabilistic seismic hazard analysis to assess the validity of their deterministic estimates of peak horizontal accelerations for the LOFT and NWCF. The maximum lower-bound

Mercalli intensity predicted for a site at the INEL regardless of service life was between intensities VII and VIII. The upper bound was a maximum Mercalli intensity between VIII and IX at a probability of 0.01%. These values correspond to peak horizontal accelerations of 0.1 and 0.4 g, respectively (Agbabian Associates, 1977).

The WCC (1979) study for the Transient Reactor Test Facility (TREAT) noted that the empirical relationships used were conservative and that consideration of the regional geology, most notably the "postulated" low-velocity alluvial interbeds within the basalt, could result in a less conservative family of attenuation curves (hence lower peak acceleration values). At a distance of approximately 30 km, a peak horizontal acceleration on bedrock of 0.22 g at the TREAT facility was estimated. Rupture of the Arco scarp fault at a distance of 48 km would produce peak accelerations of less than 0.20 g based on this relationship (WCC, 1979).

TERA Corporation (1984) also performed a probabilistic analysis for the INEL choosing the Argonne National Laboratory-West facility as a "demonstration" site. Their best estimates indicated peak accelerations of 0.073, 0.14 and 0.24 g with return periods of 100, 1000 and 10,000 years, respectively. Facilities closer to the Basin and Range province to the northwest including the faults associated with the Howe and Arco scarps have correspondingly higher accelerations. Based on the TERA Corporation (1984) hazard curves, the LOFT facility appears to be subject to a peak acceleration of approximately 0.36 g with a return period of 10,000 years.

In summary, the empirical and non-site-specific nature of these early deterministic ground motion estimates and the unresolved value for the maximum earthquake were primary factors motivating the study described herein. The occurrence of the 1983 Borah Peak earthquake provided a basis for evaluating seismic safety at the INEL. Additionally, the first strong motion records ever obtained at the INEL were those of the 1983 event, albeit at distances exceeding 90 km. These thirteen accelerographs, which were the closest instruments to the event, recorded peak horizontal accelerations ranging from 0.022 to 0.078 g at basement or free-field sites. In an attempt to estimate near-field accelerations, Jackson and Boatwright (1987) calculated values of 0.21 to 0.54 g for distances of 18 to 11 km respectively, based on the observed attenuation of the largest aftershock. Values of 0.08 to 0.23 g were also estimated from four synthetic accelerograms for a hypothetical site 18 km southeast of the mainshock. The site geology and propagation path for these estimates, however, is appropriate for a station located within the Basin and Range province and probably not for a site within the ESRP. For further details on the development of seismic design at the INEL, see Harris (1989).

METHODOLOGY

BLWN-RVT Ground Motion Model

The BLWN ground motion model first developed by Hanks and McGuire (1981) (sometimes referred to as the stochastic model) in which the energy is distributed randomly over the duration of the source has proven remarkably effective in correlating with a wide range of ground motion observations. The BLWN model incorporates the general characteristics of the source and wave propagation as well as propagation path and site effects (Figure 2). The model is appropriate for an engineering characterization of ground motion since it captures the general features of strong ground motion in terms of peak acceleration and spectral composition with a minimum of free parameters. The methodology is especially effective in the frequency range of engineering interest, 1 to 10 Hz. The ground motion model uses an ω-square Brune source model with a single-corner frequency and a constant-stress parameter. RVT is used to relate rms (root-mean-square) values of peak values of acceleration and oscillator response computed from the power spectra to expected peak time domain value. Details of the methodology are described in Volume II.

Finite Fault Methodology

A critical element in the BLWN-RVT methodology as used in this study is the assumption of a point source for the earthquake source. Given the nature of an earthquake rupture over a finite fault plane, the validity of assuming a point source for a M 6.9 earthquake at the distances of 10 to 27 km is an issue. Studies by Silva and Darragh (1990) have shown that the spectral content of earthquakes as large as M 8.1 at distances as close as 16 km can be modeled quite well for engineering design based on the BLWN-RVT methodology. To further explore this issue, a finite fault approach has been used to model the rupture of an M 6.9 earthquake on the Lemhi fault. The result of this analysis are described in Volume II. In summary though, the results of assuming a point source are conservative with respect to modeling finite faulting with the rupture initiation at the bottom southwest corner of the fault and the rupture propagating to the northwest as was the case for the 1983 Borah Peak earthquake (see following section on Earthquake Source Parameters). For a hypocenter at the northern end of the fault with unilateral rupture to the southeast, it is unclear whether the ground motions from a point source closest to the INEL sites are conservative because of possible directivity effects.

SEISMIC ATTENUATION AND SITE RESPONSE SURVEY

In early February 1989, the first of 16 stations of the seismic survey were installed at the INEL (Figures 1 and 3; Table 2). Severe cold weather which delayed installation, hindered access, and caused instrument malfunctions and the need to calibrate each site resulted in the network not becoming fully operational until mid-April. All stations were removed in mid- to late July. The 16 stations were generally installed either at or near facilities of interest (Figure 1). A desire to have recording stations located on a variety of subsurface geologies was also considered in the site selection. The need to avoid high levels of ground noise due to activities associated with the operations at the INEL and to be near a well or borehole from which detailed information on the subsurface geology beneath each station was available, governed the exact station locations. Final locations were determined using a portable Satellite Navigation System.

Each site was installed with a Sprengnether DR-100 digital event recorder and an orthogonal three-component set of Mark Products L-4C 1.0 Hz seismometers. At two sites, Teledyne-Geotech S-13 1.0 Hz seismometers were used. Data were recorded at 100 sps per channel and bandpass-filtered between 0.2 and 30 Hz. The seismometers were generally buried to a depth of 1 m to minimize wind noise. Power was provided by external batteries charged by solar panels. Digital cassette tapes were generally changed every two days and the internal clocks of the DR-100's calibrated with a portable reference clock. Calibration of the digital seismographs was performed at the beginning, middle and end of the survey. False triggering due to wind, vehicular, aerial and other cultural noise was a continual problem for most of the survey stations.

From mid-April to mid-July 1989, a total of 36 earthquakes were recorded resulting in 113 records. Hypocentral and magnitude data for the recorded earthquakes have been provided by the University of Utah Seismograph Stations (UUSS), the Montana Bureau of Mines and Geology (MBMG) and the U.S. Bureau of Reclamation (USBR). These agencies operate the Utah regional network, the Montana network and the Teton network, respectively. A few events, principally in the Borah Peak area, were located by the INEL Seismic Network. The largest earthquakes were two events greater than M_L 4 that occurred near Blue Springs Hill in northernmost Utah (Appendix B). They were recorded on nine stations each; however, their records were generally off-scale and were not used in the analysis.

INPUT PARAMETERS

For the estimation of strong motion parameters based on the BLWN-RVT methodology, a characterization of the earthquake source, propagation path and site geology parameters are required. The following is a description of those parameters.

Earthquake Source Parameters

The 1983 Borah Peak earthquake occurred on the Lost River fault which is one of three northwest-trending Basin and Range normal faults northwest of the INEL. Including the Lemhi and Beaverhead faults, all three faults show evidence for repeated Quaternary occurrences of large magnitude earthquakes along their lengths. Because of these similarities, an earthquake similar to the 1983 Borah Peak earthquake but occurring along the southern segment of the Lemhi fault near the town of Howe was assumed as the maximum earthquake pertinent to seismic safety (Figures 1 and 3). For the BLWN-RVT approach, the earthquake on the Howe segment was assumed to be of M 6.9 and have a stress parameter of 50 bars (see discussion on Stress Parameters in Volume II). A hypothetical rupture plane was assumed to be a 45° southwest-dipping normal fault with an initial point of rupture (for the finite fault modeling) at the southern end of the fault at a depth of 16 km identical to the 1983 Borah Peak earthquake (Figure 1). The point source in this study was assumed to occur at the closest point on the rupture plane to each site. Thus source-to-site distances ranged from 11 to 27 km (Figure 1).

Based on an empirical relationship for fault rupture length versus magnitude, Turko (1988) has estimated a maximum earthquake of M_S 6.9 for the Howe segment based on an estimated 23-km length (Figure 1). A conservative assumption of a maximum magnitude of M 6.9 (M_S 7.3) incorporates the estimated uncertainty in the definition of this segment and the assumption that only this segment will rupture in a maximum event. Paleoseismic studies are currently in progress to evaluate the maximum earthquake and its recurrence on the Howe and Fallert Springs segments, the two segments on the Lemhi fault closest to the INEL (WCC, 1990).

Propagation Path Parameters

For the propagation path between the point source and the sites, a half-space model was assumed characterized by a shear-wave velocity (V_s) of 3.55 km/sec and a density of 2.7 g/cm^3 based on Sparlin et al. (1982). Based on an analysis of L_g waves recorded at a seismographic station in Hailey, Idaho, Singh and Herrmann (1983) determined a regional crustal coda Q_o of 450 and an η of 0.2 for the frequency-dependent quality factors Q(f). These values were considered to be average values since it is unlikely that the Q_o and η are the same for both the Basin and Range Province and Snake River Plain. For example, Braile et al. (1982) observed high attenuation in a seismic refraction experiment within the ESRP and they attribute it to low Q values in the volcanic rocks (Q_p 20 to 200) and throughout the crust (Q_p 160 to 300) where Q_p is the P-wave quality factor. In lieu of any other available data and the need to use Q(f), a Q(f) of 450 and an η of 0.2 was assumed appropriate for this study. Given the relatively short source-to-site distances being considered (less than 30 km), however, attenuation along the propagation path is probably not significant especially compared to attenuation by the near-surface geologic structure.

The BLWN-RVT methodology has been very successful in capturing the essential engineering aspects of strong ground motions although it treats the problem in a one-dimensional manner. Many other strong motion studies have also shown that one-dimensional estimates are quite successful in matching observed data. However, the crust beneath the eastern Snake River Plain has two-dimensional variations (see Figure 13; Sparlin et al., 1982) and structures within such a crust could effect strong ground motions. For example, preliminary studies suggest that features such as the high velocity, possibly mafic body beneath the Plain may increase strong ground motions depending on the source-to-site distance, focal depth of the earthquake and the specific location and geometry of the mafic body (Walter Silva, Pacific Engineering and Analysis, personal communication, 1990). Future studies will attempt to address this issue.

Site Parameters

Three site parameters need to be specified as a function of depth for the BLWN-RVT model: V_S, Q_S and the density (ρ) (Figure 2). Geologic profiles for each site were developed based on lithologic, sonic velocity and density data from boreholes, lab measurements of core samples, and the analysis of ground motions from the Borah Peak mainshock and recorded regional events (Appendix A).

Much of what is known about the subsurface geology beneath the INEL is based on the 2.8 km-deep INEL-1 borehole. The lithologic log of INEL-1 shows that at least 52 distinctive layers were encountered (Doherty et al., 1979) (Figure 4). The upper section above a depth of 745 m consists of basaltic lava flows with interbedded sediments of alluvial, lacustrine, eolian and volcanic origin. The lower section based upon the lithologic log consists exclusively of rhyolitic welded ash-flow tuffs, airfall ash deposits, nonwelded ash-flow tuffs and volcaniclastic sediments. However, inspection of the INEL-1 core by Dick Smith (EG&G Idaho, Inc.) suggests that the interbeds within the welded tuff previously identified as tuffaceous interbeds are instead a devitrified rhyolite. A thick (87 m) unwelded airfall tuff layer occurs atop the welded tuff sections. At a depth below approximately 2460 m, a rhyodacite porphyry was encountered (Doherty et al., 1979).

A borehole sonic log of the INEL-1 hole was performed by Schlumberger to measure sonic P-wave velocities. Unfortunately, no velocity measurements were made in the top portion of the well to a depth of approximately 400 m and velocity measurements above 1082 m were within the casing. Thus no measurements from INEL-1 are available for the basalt section and its interbeds. However, a few reliable sonic velocity and density measurements were available for the basalt section in Corehole 2-2A, the 915-m deep hole northeast of INEL-1 (Figure 1). These values formed the basis for estimating the velocities and densities in the basalt section beneath each site.

An examination of the caliper as a function of depth in INEL-1 suggests that only in specific zones in the stronger rock, generally the welded tuff and rhyodacite, were reliable downhole sonic velocity and density measurements made. Thus preliminary sonic velocities and densities assigned to the welded tuff layers in the geologic profiles were generally estimates based upon a limited number of actual measurements (and these were made in the most competent rock) as was the case for the basalt layers in Corehole 2-2A). Increases in both V_s and density with depth were incorporated into these estimates to account for the increase in lithostatic pressure. For the rhyodacite, numerous reliable measurements were made so the assigned velocities are probably quite accurate.

No downhole geophysical data were available for the velocities and densities of the devitrified rhyolite, the unwelded airfall tuff above the welded tuff, and the cinders and unconsolidated sedimentary interbeds within the basalt section. However, a total of 12 core samples were submitted to Terra Tek Inc. (1989) for ultrasonic velocity (both P- and S-wave) and bulk density measurements. Of these, nine samples were successfully tested including cores of basalt, welded tuff, sedimentary interbeds and devitrified rhyolite. The samples were water-saturated prior to testing and tested under confining pressures and temperatures simulating the in situ conditions. The lab results were used to constrain the preliminary V_s and density values assigned to the INEL-1 geologic profile.

In some cases, V_s values were estimated from the P-wave velocities based on an assumed Poisson's ratio for each general rock type. A typical Poisson's ratio of 0.25 was assumed for the stronger and denser rocks, the welded tuff and rhyodacite, which compose most of the profile. A somewhat higher value of 0.30 was assumed for basalt because of its fractured nature and 0.35 for the devitrified rhyolite.

For the three soil sites in this study (SIS, ANL and LOFT), we have assumed for the Lost River flood-plain sands, silts, and gravels overlying the basalt a V_s of 0.41 km/sec and a density of 2.00 g/cm^3 based upon lab measurements and in-situ measurements as reported in several geotechnical reports for facilities at the INEL. The soil thicknesses at SIS, ANL and LOFT were 12.2 m, 6.1 m, and 17.9 m, respectively. The soil was allowed to behave in a nonlinear manner at high strain levels. Modulus reduction and damping curves developed by Toro et al. (1988) were considered appropriate for modeling the soil at the INEL.

Figure 4 shows the S-wave velocity model developed for the INEL-1 site and three existing simplified velocity profiles for the ESRP. The three existing models are consistent with our detailed profile. In general, the INEL-1 velocity model shows a relatively small velocity gradient (velocities do not increase rapidly with depth) compared to a typical western U.S. rock site. This absence of a strong gradient reduces the amplification that normally results from such near-surface gradients.

RESULTS

Development of Velocity Models

The geologic profile for the INEL-1 site (Figure 4) provided the basis for development of the other geologic profiles although the lack of information on the deeper stratigraphy beneath the other sites necessitated some significant assumptions. The well nearest each site provided detailed geologic data down to approximately 200-300 m (Table 3). Since none of these wells penetrated the complete basalt section, total basalt thicknesses were estimated by Dick Smith (EG&G) based upon a basalt isopach map interpreted from geophysical data (Whitehead, 1986) and data from the

INEL-1 borehole and Corehole 2-2A. It was assumed that beneath the basalts, the interbedded welded-tuff section in the INEL profile is representative of the stratigraphy in the ESRP and this section was attached to each site profile. The thick low-velocity unwelded airfall tuff between the basalt and the welded tuffs was not included at the other sites due to the lack of information on its lateral extent. In the absence of information on the interbeds in the lower basalt at sites other than INEL-1, that section was initially treated as homogeneous basalt. Information on the site-specific attenuation (κ) was obtained from modeling spectra of selected regional earthquakes, and interbeds were placed in the lower basalt of some of the velocity models to accommodate this additional constraint (see Volume II).

The values of Q_s in the INEL-1 model were partially constrained by the regional values of Braile et al. (1982) who obtained an average Q_p of about 30 for the upper crust. A functional form of Q_s with velocity was adopted to provide an increase in Q_s with depth. This relation was further constrained by comparison of BLWN-RVT Fourier spectra and the spectra from regional events. For the basalts and sedimentary interbeds, we used $Q_s = 0.015 \cdot V_s$ and for the welded-tuff section, $Q_s = 0.08 \cdot V_s$ (m/sec). These relationships were used in the other geologic profiles to derive the Q_s structure. Details on other aspects of the development of the geologic profiles beneath each site is discussed in Volume II.

Site-Specific Ground Motion Estimates

Site-specific values of peak horizontal ground acceleration and acceleration response spectra (16th, 50th and 84th percentile and 2%, 5% and 10% damped of the median) (Tables 4 and 5; Figures 5 to 28) have been computed for the Howe earthquake based on the 12 geologic site profiles (Appendix A). To assess the effects of the uncertainties in the source, propagation path and site parameters used in these estimates, a parameter analysis of the predicted ground motion for each of the sites has also been performed (see Volume II). For the source, the stress parameter was varied to 25 and

100 bars from the standard value of 50 bars. The Q_s of each layer was increased and decreased by a factor of 2. V_s were varied similarly, using a factor of 1.3 for the sedimentary interbeds in the basalt and soils (if any) and a factor of 1.1 for the rocks. Both V_s and Q_s were first varied in the unsmoothed geologic profiles and then the profiles were smoothed (except for the surficial soil layers at the soil sites). The different velocity variations between the sediments and rock reflect a greater uncertainty in the sediment velocities. When the velocities were changed independently of the Q values, or vice versa, the functional dependence of Q on V_s was also inherently changed. The peak horizontal accelerations for the various parameter variations are listed in Table 9, Volume II. The estimated uncertainties in the Q_s of the geologic profiles have the most significant impact on the site-specific response spectra. An increase in Q_s by the factor of two can result in an increase in peak horizontal acceleration by as much as 33% (Volume II). Of slightly lesser importance is the uncertainty in the stress parameter. A stress parameter of 100 bars increases the peak horizontal acceleration based on a 50 bar stress parameter by an approximate factor of 1.7 (Volume II). The estimated uncertainties in V_s of the sediments and to a greater degree, in the rock V_s have minimal effects on the predicted strong ground motions.

The 5% damped absolute acceleration response spectra for each site were assumed to be generally log-normally distributed, and estimates of the 16th, 50th and 84th percentiles of the distribution were made. In order to determine the 16th, 50th and 84th percentile spectra, the value of each parameter used in the parameter variations was assigned a weight based on the estimated probability that it is the correct value. For the stress parameter of the Howe event, values of 25, 50 and 100 bars were assigned weights of 30%, 50% and 20%, respectively. The low, standard and high layer Q_s values were assigned weights of 10%, 80% and 10%, respectively. The low, standard and high values of the rock V_s were 20%, 60% and 20%, and 25%, 50% and 25% for the interbed and soil V_s. Based on analyses using every possible combination of these weightings, the 16th, 50th and 84th percentile spectra were then computed for the NPR site. The NPR median spectrum that was obtained is very similar in spectral shape to the standard spectrum (with standard parameters), but slightly lower in overall level. For example, the peak horizontal ground acceleration for the standard model was 0.155 g compared to the median value of 0.145 g. Thus the standard spectrum is a conservative estimate relative to the median spectrum. We therefore assumed that the standard spectrum at each of the other sites was equivalent to the median spectrum. The standard deviation obtained from the NPR estimates was adopted for the other sites, since we consider the weighting chosen in those parameter variations to be conservative. These frequency-dependent standard deviations for NPR were used to produce the 16th and 84th percentile spectra for all the other sites.

The median, 16th and 84th percentile peak horizontal accelerations are listed in Table 4. The values range from 0.09 g at RWMC to 0.40 g at LOFT for a distance range of 27 to 10 km. The largest ground motions for all the sites at the INEL, as depicted in the acceleration response spectra and peak horizontal acceleration, is in the area of LOFT (Table 4). This is expected, given that LOFT is the closest site (10.7 km) to the Howe earthquake. Additionally the relatively thick soil layer (17.8 m) overlying the basalt appears to significantly amplify the ground motions by a factor of 1.4 relative to the rock site.

FPR and SIS, which are sites within 500 m of each other, and thus at nearly the same distance to the Howe earthquake show markedly different ground motion levels due principally to the amplifying effects of the 12.2 m-thick soil at SIS (Table 4). A comparison of the corresponding peak ground accelerations suggests an amplification factor of approximately 1.5 (some of this may be attributed to the slight difference in κ). Similarly, the rock and soil ground motions at ANL (soil thickness 6.1 m) shows an amplification of the peak horizontal ground acceleration of 1.64. This is consistent with the empirically-based amplification factor of approximately 1.5 suggested by Campbell (1989) for thin soil sites.

Note that sites in Table 4 are listed in order of increasing distance and that even without the soil sites, there are obvious exceptions to a general decrease in peak accelerations. For example, INEL-1 has a somewhat low value probably due to the high κ in its extensively interbedded geologic profile. Both the ANL rock site and ATR have relatively high peak horizontal accelerations because of their low κ values. The low κ for ANL is probably due to the near-absence of sedimentary interbeds beneath the site because the site is relatively distant from the Lost River drainage (Table 4). The low κ for ATR is rather anomalous and will require further subsurface investigations.

For comparison, the median values derived by the empirically-based peak acceleration-attenuation relationships of Campbell (1989) and Joyner and Boore (1988) have been computed and are shown in Table 5. Both relationships are based principally on western U.S. strong motion data. Comparing the predicted and empirical peak accelerations, only the BLWN-RVT values at the two soil sites at LOFT and SIS exceed the Joyner and Boore (1988) estimates. This is reasonable considering two factors: (1) the Joyner and Boore (1988) relationship assumes a focal depth of 8 km which is significantly less than the modeled 16 km depth used in this study. This effectively results in shorter Joyner and Boore source-to-site distances and hence higher peak accelerations; and (2) the generally slightly lower κ values for the INEL sites and absence of a strong positive velocity gradient relative to a typical western U.S. rock site produce lower peak accelerations. The predicted peak accelerations are also generally lower than the Campbell (1989) values although not significantly for the soil site at ANL and the rock sites at NRF, LOFT, ATR, NPR, and ANL. The significantly higher predicted value for the soil site at LOFT is due to the empirical relationships not accounting for near-surface amplification from the soil layer.

Peak Acceleration-Attenuation Curves

Peak horizontal acceleration-attenuation curves were generated for the INEL-1 and ATR sites from the closest approach of the sites to the Howe earthquake (M 6.9) out to a distance of 100 km (Figure 29). The distance defined is the shortest distance to the hypothetical rupture plane. The two sites were chosen because they may reflect the range of peak horizontal accelerations for sites at the INEL. The INEL-1 geologic profile has the highest κ (0.037 sec) of all the sites compared to the low κ (0.01 sec) for ATR. Thus these κ values may represent the two possible extremes in shallow crustal attenuation. The unconstrained relationship of Campbell (1989) is shown for comparison. The Joyner and Boore (1988) curve is not shown on this figure because of their different definition of distance (horizontal distance to the vertical projection of the rupture plane). Additionally Figure 30 shows peak horizontal acceleration-attenuation curves for M 5.5, 6.5 and 7.5 also specific to the INEL-1 and ATR sites.

CONCLUSIONS

Strong earthquake ground motions have been estimated for 12 sites at the INEL assuming that an event similar to the 1983 M 6.9 Borah Peak earthquake occurs along the southern segment of the Lemhi fault. The strong ground motion parameters have been estimated based on a methodology incorporating the BLWN ground motion model coupled with RVT. A 16-station seismic attenuation and site response survey utilizing three-component portable digital seismographs was also performed for a five-month period in 1989. Based on strong ground motion records of the 1983 Borah Peak earthquake and recordings of other regional earthquakes, the seismic attenuation in the shallow crust (κ) and local site response have been evaluated. These data combined with geologic profiles developed for each site based principally on shallow borehole data, were used in the estimation of the strong ground motion parameters. The peak horizontal ground accelerations for individual sites range from 0.09 to 0.40 g at distances of 27 to 10 km (Table 4). The Q_s in the geologic profiles and the stress parameter of the modeled earthquake are significant factors that can control strong ground motions at a site. As additional and improved information on the geology beneath each facility becomes available, these strong ground motion estimates will be refined.

An important point to consider relevant to the results of this study is that the estimated strong ground motions may not be the "worst case" motions. Studies are currently underway to determine if the 1983 Borah Peak earthquake is a reasonably conservative earthquake to use for seismic safety analyses and design. In addition, the placement of the point source at a position on the postulated rupture plane of the Howe segment closest to the sites provides conservative estimates with the possible exception of one case. If the rupture of a Howe earthquake were to initiate at a point away from the southern edge of the rupture plane, strong ground motions could be enhanced by directivity effects. Such effects have been infrequently observed and are not well understood. Future geologic studies have been proposed to evaluate the rupture characteristics of past earthquakes on the southern Lemhi fault.

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TABLE 1

INPUT PARAMETERS

Parameter	Values
M	6.9
$\Delta\sigma$	50 bars
R	11 to 27 km
V_s	3.55 km/sec
ρ_s	2.7 gm/cm^3
Q_o	450
η	0.2
Site Parameters (V_s, Q_s and η)	See geologic profiles (Appendix A)

TABLE 2

REGIONAL EARTHQUAKES RECORDED BY THE SEISMIC SURVEY

No.	Date 1989	Origin Time (UTC)	Latitude	Longitude	Depth (km)	Magnitude	Location	Source of Location
1	21 Apr	0926 53.5	44°26.2'	114°13.6'	6.1	M_c 2.3	Challis, ID	MBMG
2	29 Apr	2113 55.0	42°38.6'	111°37.5'	6.3	M_c 1.5	Soda Springs, ID	UUSS
3	1 May	1424 08.3	44°41.8'	112°02.0'	6.7	M_c 2.2 M_L 2.5	Centennial Mts, MT	MBMG
4	2 May	1008 26.5	43°58.5'	111°00.0'	10.9	M_c 2.5	West of Jackson Lake, WY	USBR
5	2 May	1045 03.8	42°38.8'	111°38.5'	6.9	M_c 2.0	Soda Springs, ID	UUSS
6	2 May	2008 30.8	42°39.5'	111°39.2'	1.2	M_c 2.0	Soda Springs, ID	UUSS
7	8 May	0921 12.8	44°29.6'	114°20.6'	17.8	M_c 3.0 M_L 3.2	Challis, ID	MBMG
8	9 May	0629 17.8	44°10.6'	110°41.3'	9.8	M_L 3.1	Yellowstone, WY	UUSS
9	22 May	1005 51.2	43°30.7'	110°44.4'	5.2	M_c 3.0	Jackson, WY	USBR
10	23 May	1333 37.7	44°32.5'	112°14.6'	1.1	M_c 2.6 M_L 3.2	Monida Pass, ID	MBMG
11	29 May	0349 12.8	44°37.2'	112°06.6'	1.7	M_c 2.6 M_L 3.0	Centennial Mts, MT	MBMG
12	6 Jun	2002 34.7	44°46.7'	111°30.5'	4.1	M_c 2.9 M_L 3.5	Hebgen Lake, MT	MBMG
13	7 Jun	0906 43.9	44°02.2'	113°40.9'	0.2	M_c 1.3	Borah Peak, ID	INEL
14	8 Jun	2330 43.7	44°35.5'	115°06.4'	13.2	M_c 3.0 M_L 2.8	45 km NW of Stanley, ID	MBMG
15	10 Jun	1943 27.3	44° 25.8'	114°15.7'	16.3	M_c 1.6	Challis, ID	INEL

TABLE 2
(continued)

No.	Date 1989	Origin Time (UTC)	Latitude	Longitude	Depth (km)	Magnitude	Location	Source of Location
16	14 Jun	2242 54.8	42°41.3'	111°28.5'	3.2	M_C 2.5	Soda Springs, ID	UUSS
17	15 Jun	1509 33.4	41°41.9'	111°28.9'	1.5	M_C 2.5	Soda Springs, ID	UUSS
18	16 Jun	2225 22.8	45°42.3'	111°22.1'	1.3	M_C 3.2 M_L 3.6	15 km SW of Manhatten, MT	MBMG
19	18 Jun	0331 17.8	44°47.6'	111°10.4'	2.0	M_C 2.7 M_L 2.7	Hebgen Lake, MT	MBMG
20	20 Jun	1119 55.6	44°19.7'	114°01.2'	0.9	M_C 0.9	Borah Peak, ID	INEL
21	21 Jun	2154 18.6	41°42.5'	112°22.4'	7.8	M_C 3.4 M_C 4.1	Blue Springs Hill, UT	UUSS
22	22 Jun	0032 59.2	44°10.6'	113°10.6'	0.3	M_C 1.5	Lemhi Range, ID	INEL
23	23 Jun	1126 22.5	44°39.8'	114°07.6'	5.3	M_C 2.3	18 km NE of Challis, ID	MBMG
24	24 Jun	0924 50.0	43°30.5'	110°44.5'	5.2	M_C 3.7 M_L 3.7	Jackson, WY	USBR
25	24 Jun	1025 16.0	43°30.4'	110°44.3'	5.4	M_C 3.6	Jackson, WY	USBR
26	24 Jun	2032 52.6	43°30.2'	110°44.3'	5.6	M_C 2.9	Jackson, WY	USBR
27	24 Jun	2209 21.7	45°03.2'	112°59.3'	7.5	M_C 2.5 M_L 2.7	Clark Canyon Reservoir, MT	MBMG
28	27 Jun	1551 49.7	41°47.7'	112°44.0'	5.6	M_C 2.7 M_L 3.0	Hansel Valley, UT	UUSS
29	27 Jun	1628 29.2	41°47.7'	112°43.8'	5.5	M_C 2.8 M_L 2.9	Hansel Valley, UT	UUSS
30	27 Jun	1825 09.0	43°30.4'	110°44.2'	5.5	M_C 2.9	Jackson, WY	USBR

TABLE 2
(continued)

No.	Date 1989	Origin Time (UTC)	Latitude	Longitude	Depth (km)	Magnitude	Location	Source of Location
31	28 Jun	0316 38.4	44°38.4'	112°20.7'	1.1	M_C 2.6 M_L 3.1	West Centennial Valley, MT	MBMG
32	3 Jul	2221 12.7	44°05.5'	114°24.0'	5.0	M_C 1.6	West of Borah Peak	INEL
33	3 Jul	2244 28.7	41°42.4'	112°22.4'	7.4	M_C 4.5 M_L 4.8	Blue Springs Hill, UT	UUSS
34	5 Jul	2251 56.4	41°42.4'	112°22.3'	10.0	M_L 4.6	Blue Springs Hill, UT	UUSS
35	7 Jul	0519 17.0	44°09.4'	113°52.7'	1.3	M_C 1.8	Borah Peak, ID	INEL
36	12 Jul	1947 20.8	44°31.7'	113°56.4'	23.3	M_C 2.6 M_L 2.7	East of Challis, ID	MBMG

M_L Richter magnitude
M_C Coda duration magnitude

TABLE 3

SCHEMATIC GEOLOGIC PROFILES

NPR	SIS	FPR	ATR
0 m	0 m	0 m	0 m
*			
183 m	182 m	203 m	371 m
762 m	793 m	793 m	671 m
Sub-Ba**	Sub-Ba	Sub-Ba	Sub-Ba

ANL	PBF	NRF	LOFT
0 m	0 m	0 m	0 m
216 m	185 m	163 m	340 m
1189 m	762 m	488 m	845 m
Sub-Ba	Sub-Ba	Sub-Ba	Sub-Ba

RWMC
0 m
183 m
976 m
Sub-Ba

* The top portion of each profile is detailed in Appendix A.
** The Sub-Ba portions of the profiles are assumed to be the same as the interbeddded welded tuff section of INEL-1.

TABLE 4

PREDICTED SITE-SPECIFIC PEAK HORIZONTAL ACCELERATIONS
FOR THE HOWE EARTHQUAKE

Site*	Distance (km)	Peak Horizontal Acceleration (g) 16th Percentile	50th Percentile	84th Percentile
LOFT (soil)	10.7	0.268	0.404	0.608
LOFT	10.7	0.165	0.248	0.373
NRF	15.3	0.164	0.247	0.372
INEL-1	16.9	0.096	0.145	0.218
ATR	19.3	0.117	0.176	0.265
NPR	20.7	0.096	0.145**	0.219
SIS (soil)	20.8	0.131	0.197	0.297
FPR	21.4	0.086	0.130	0.196
PBF	23.4	0.074	0.112	0.169
ANL	25.9	0.089	0.134	0.202
ANL (soil)	25.9	0.141	0.213	0.321
RWMC	27.4	0.057	0.086	0.130

* All sites are rock sites at the ground surface except those designated as soil sites.

** True median value. At other sites, the median value is assumed to be approximately equivalent to value determined from the standard model.

TABLE 5

PEAK HORIZONTAL ACCELERATIONS
MODEL PREDICTIONS VERSUS EMPIRICAL MEDIAN VALUES

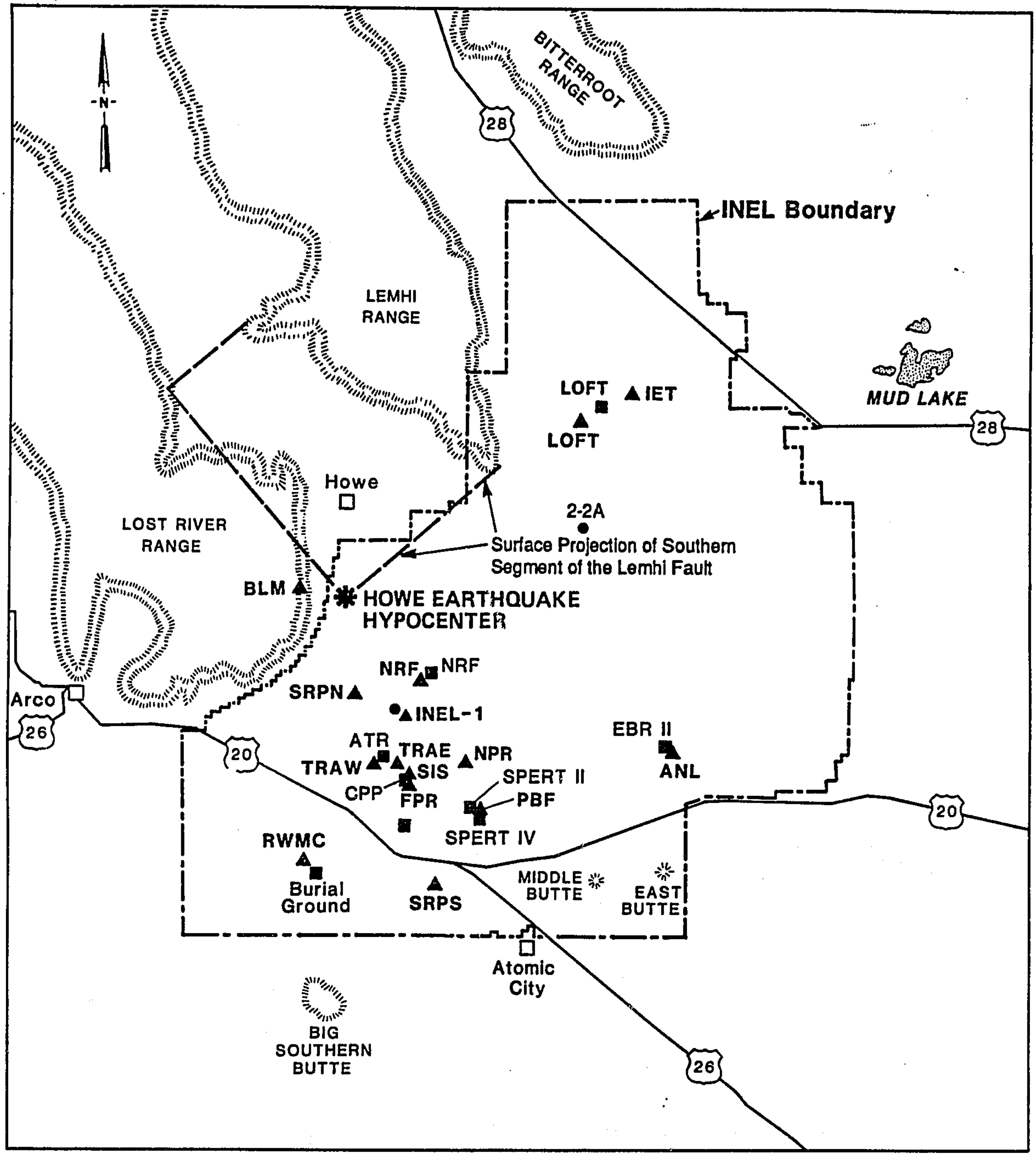
Site*	Magnitude Ms	Magnitude M	Hypocentral Distance (km)	Horizontal Distance (km)	Seismogenic Distance (km)	Rupture Distance (km)	Joyner & Boore (1988)	Campbell (1989)**	Predicted Median
NRF	7.3	6.9	18.4	9.1	15.3	15.3	0.332	0.248	0.247
INEL-1	7.3	6.9	19.2	10.7	16.9	16.9	0.299	0.228	0.145
LOFT	7.3	6.9	30.9	10.7	13.0	10.7	0.299	0.284***	0.248
LOFT (soil)							0.299	0.284***	0.404
ATR	7.3	6.9	20.7	13.2	19.3	19.3	0.255	0.203	0.176
SIS (soil)	7.3	6.9	22.1	15.2	20.8	20.8	0.227	0.190***	0.197
FPR	7.3	6.9	22.5	15.8	21.4	21.4	0.219	0.185	0.130
NPR	7.3	6.9	23.1	16.7	20.7	20.7	0.209	0.190	0.155
PBF	7.3	6.9	25.2	19.5	23.4	23.4	0.180	0.170	0.112
RWMC	7.3	6.9	27.5	22.4	27.4	27.4	0.157	0.146	0.086
ANL	7.3	6.9	30.2	25.6	25.9	25.9	0.137	0.154	0.134
ANL (soil)							0.137	0.233	0.213

* All sites are rock sites at the ground surface except those designated as soil sites.

** Unconstrained relationship.

*** These sites are not thin soil sites (10 m or less) as classified by Campbell (1989). According to Campbell, an amplification of the peak horizontal acceleration of approximately 1.5 could occur in thin soil sites.

Notes: M_S and seismogenic distance used by Campbell (1989).
M and rupture distance used by Joyner and Boore (1988).



LEGEND

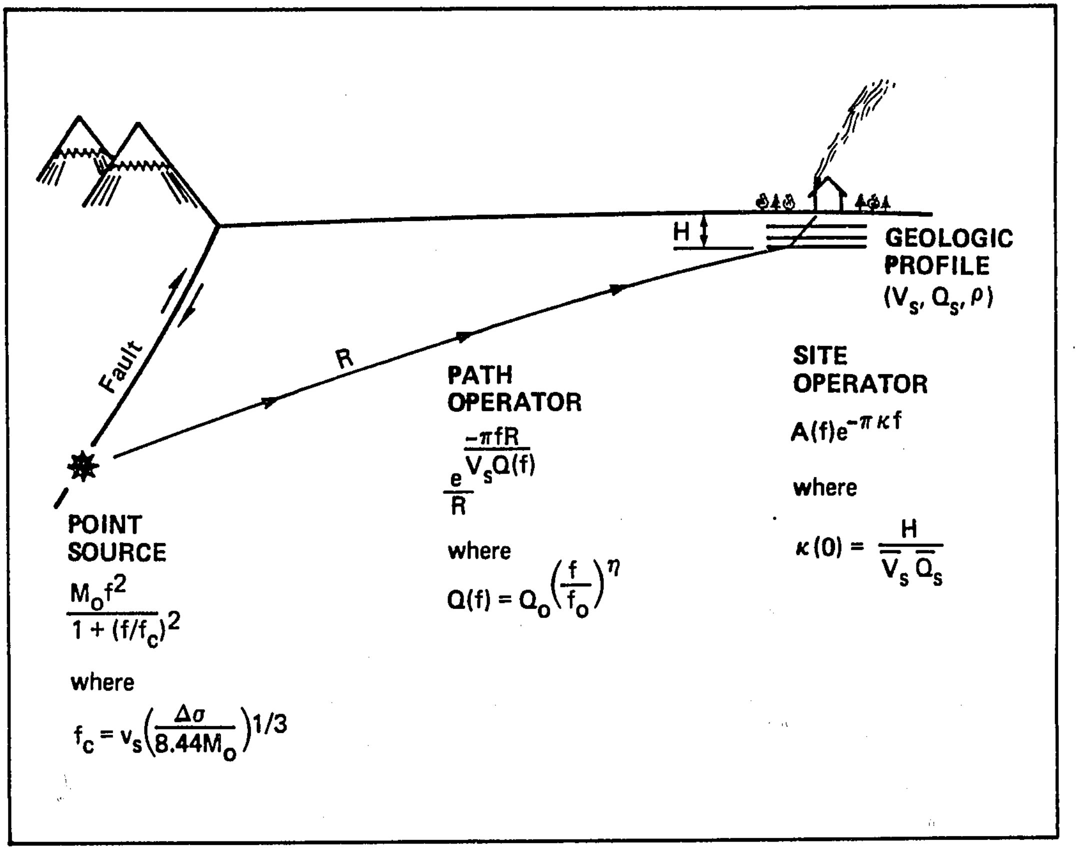
■ Facility

▲ Station

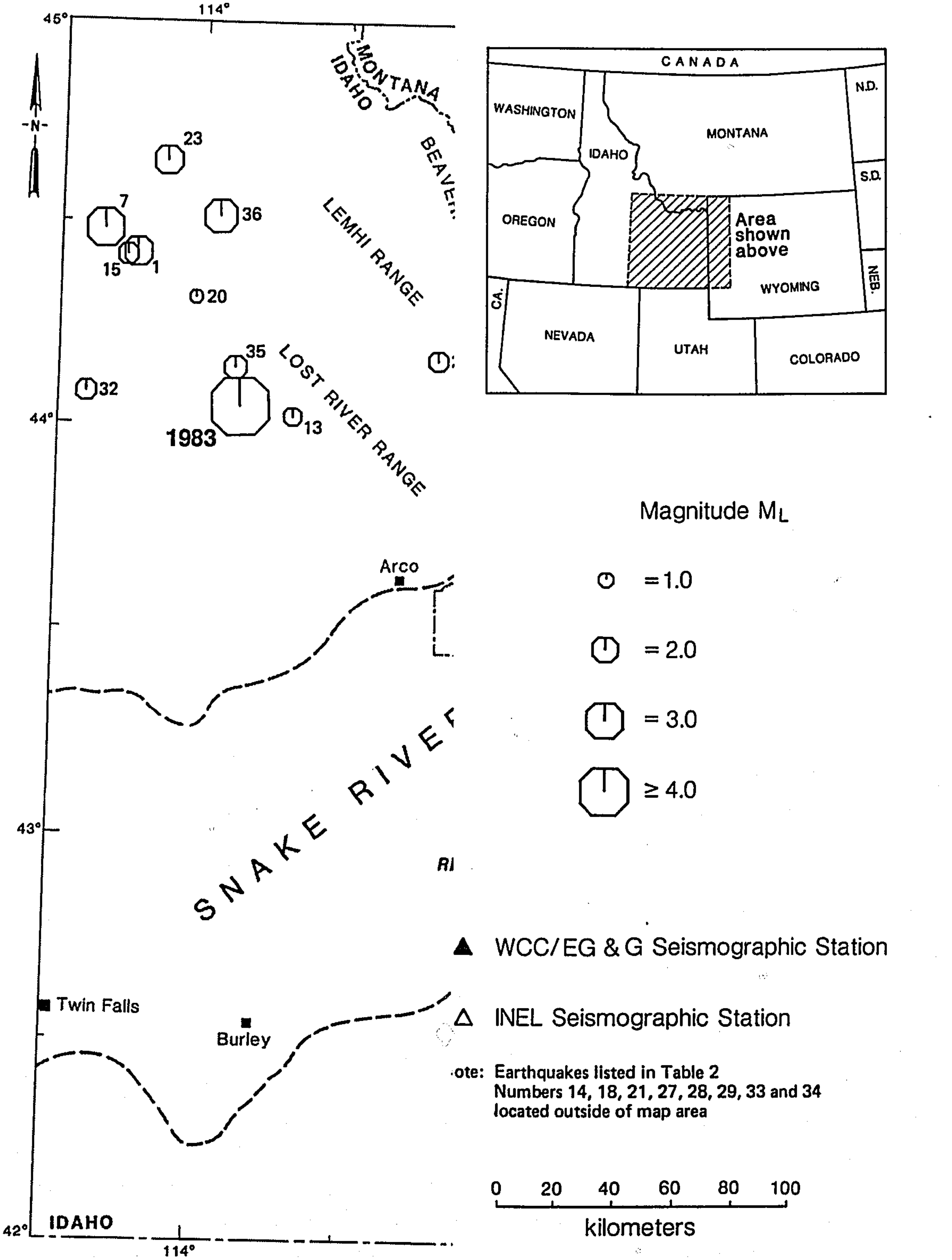
● Drillhole

0 10 20 30
kilometers

Project No. 8830035B	INEL	SEISMIC SURVEY STATIONS AND MAJOR FACILITIES AT THE INEL	Figure 1
Woodward-Clyde Consultants			

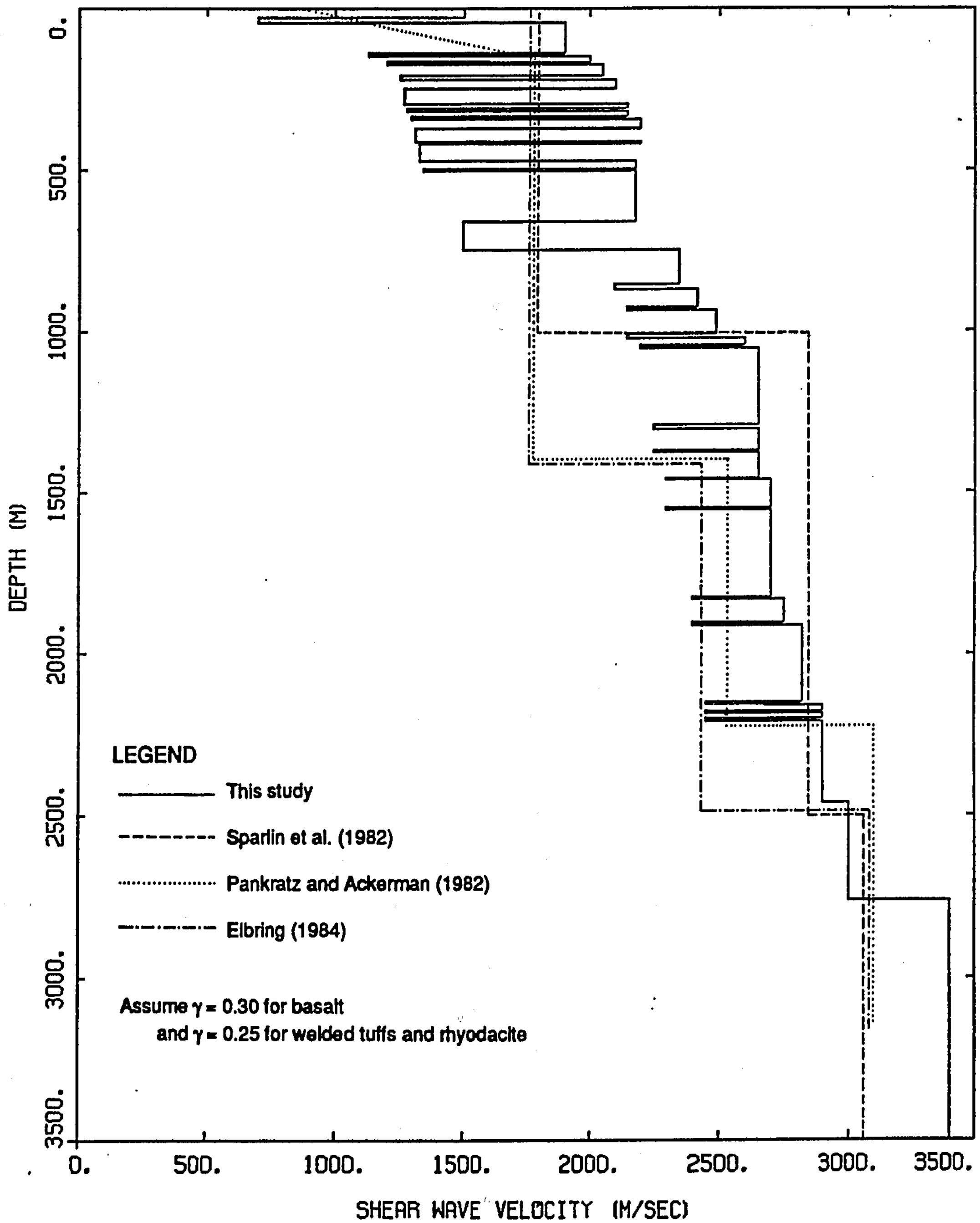


Project No. 8830035B	INEL	SCHEMATIC OF BAND-LIMITED-WHITE-NOISE GROUND MOTION MODEL	Figure 2
Woodward-Clyde Consultants			

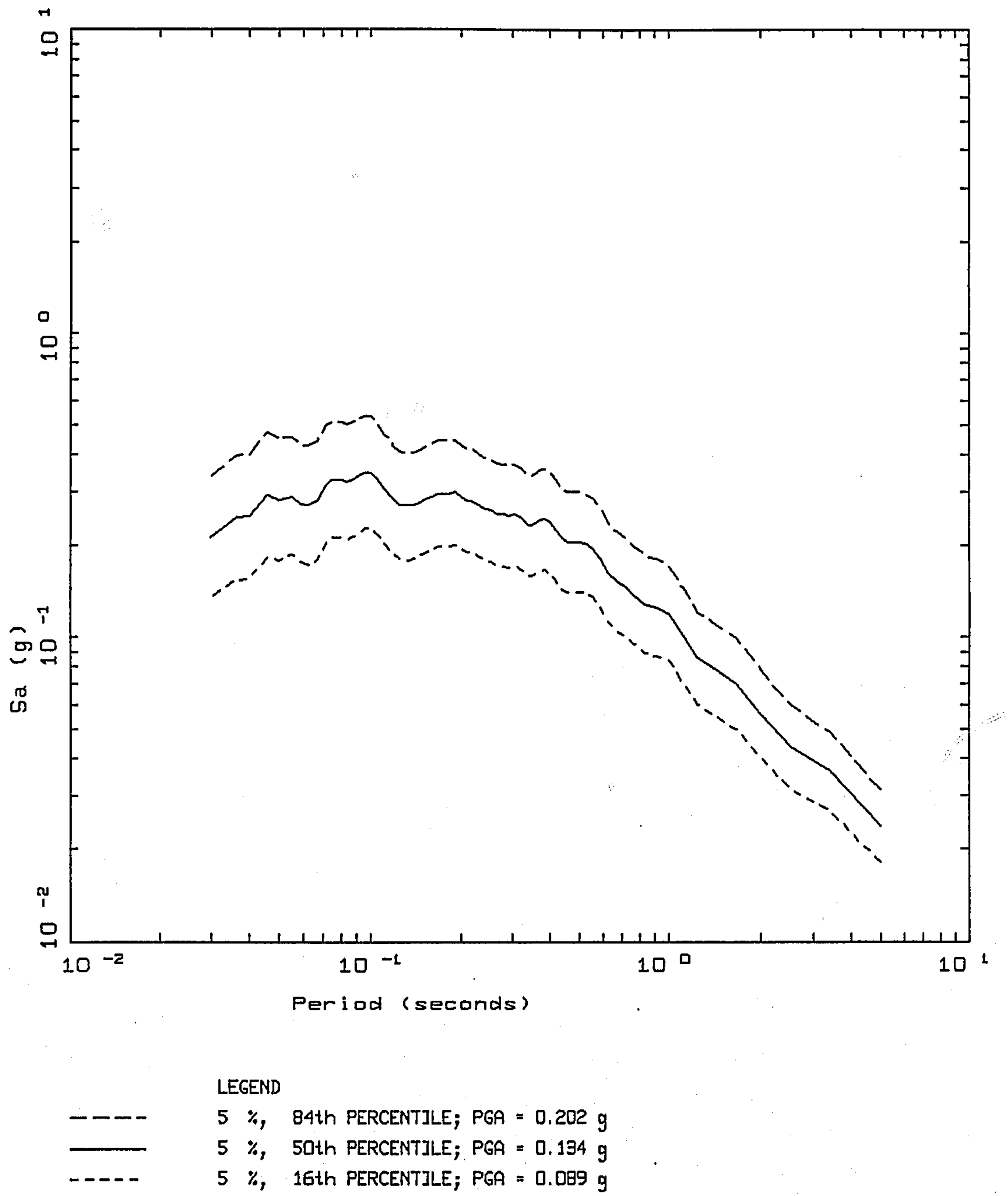


EPICENTRAL LOCATIONS OF RECORDED REGIONAL EARTHQUAKES

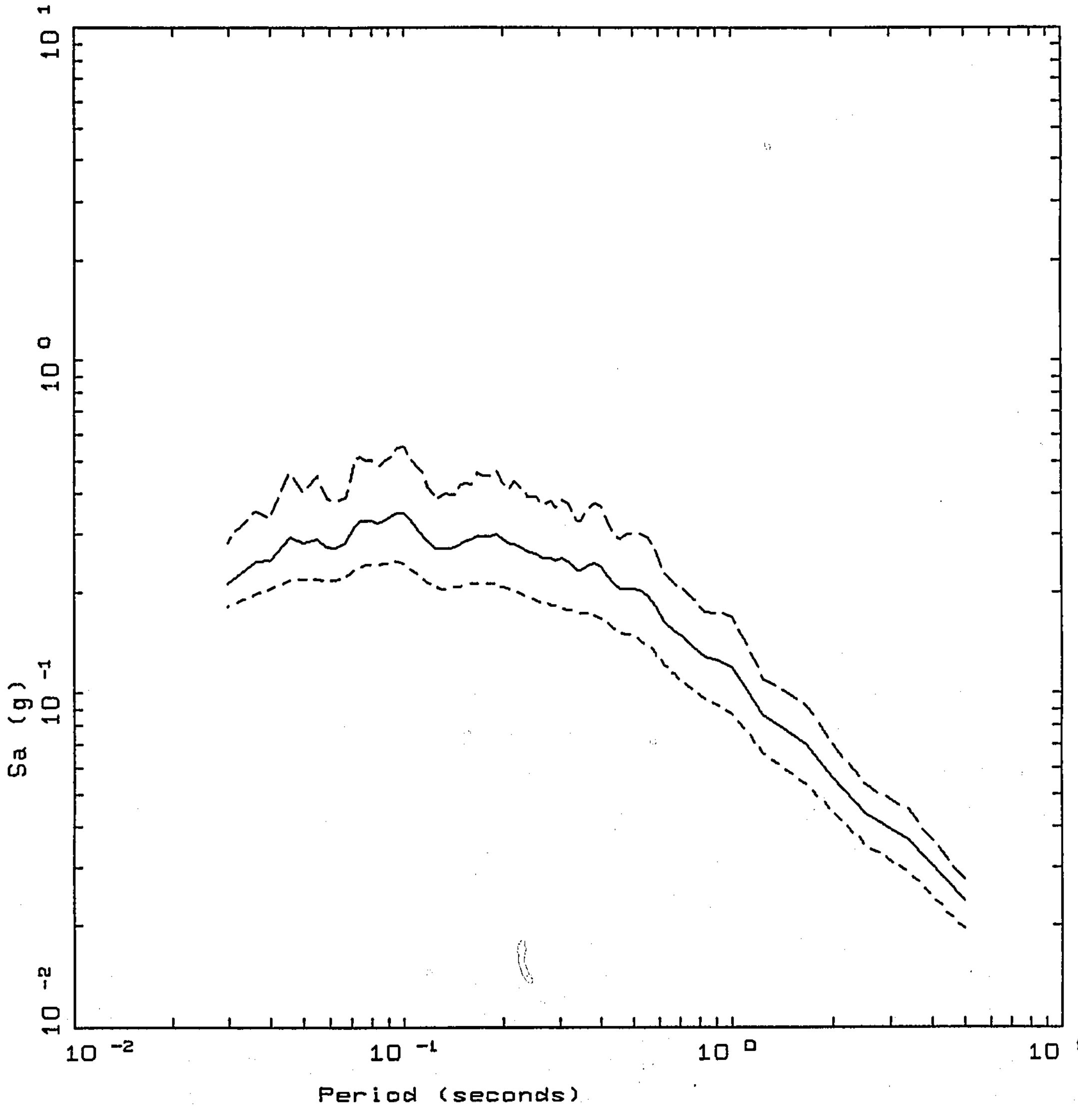
Figure 3



Project No. 8830035B	INEL	COMPARISON OF INEL-1 S-WAVE VELOCITY MODEL AND OTHER ESRP MODELS	Figure 4
Woodward-Clyde Consultants			



Project No. 8830095B	INEL	ANL RESPONSE SPECTRA ON ROCK 16th, 50th and 84th PERCENTILE	Figure 5
Woodward-Clyde Consultants			



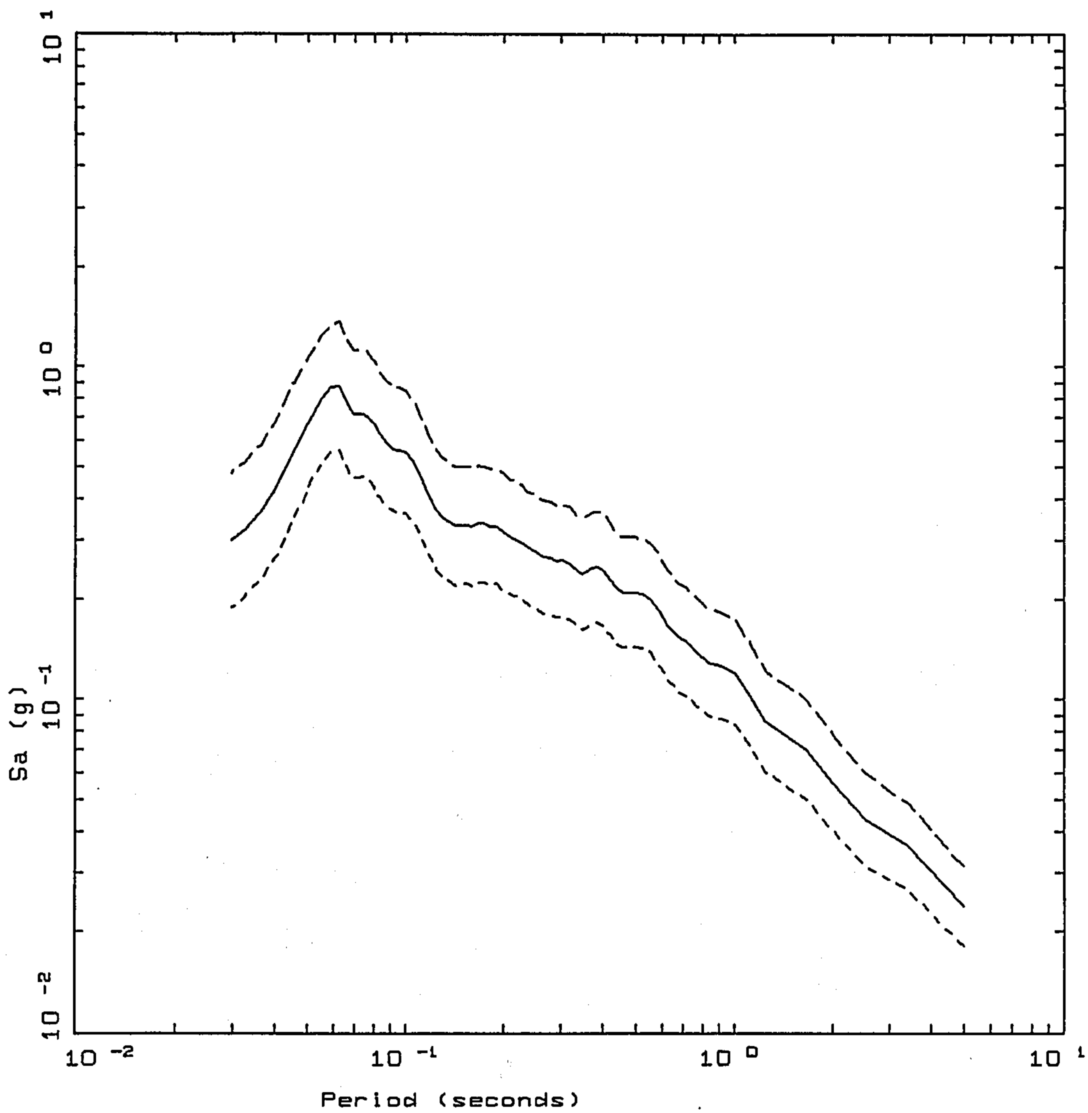
LEGEND

STANDARD MODEL, DAMPING = 5%, PGA = 0.134 g

DAMPING = 10%, PGA = 0.134 g

DAMPING = 2%, PGA = 0.134 g

Project No. 8830035B	INEL	ANL RESPONSE SPECTRA ON ROCK VARIATION OF DAMPING	Figure 6
Woodward-Clyde Consultants			



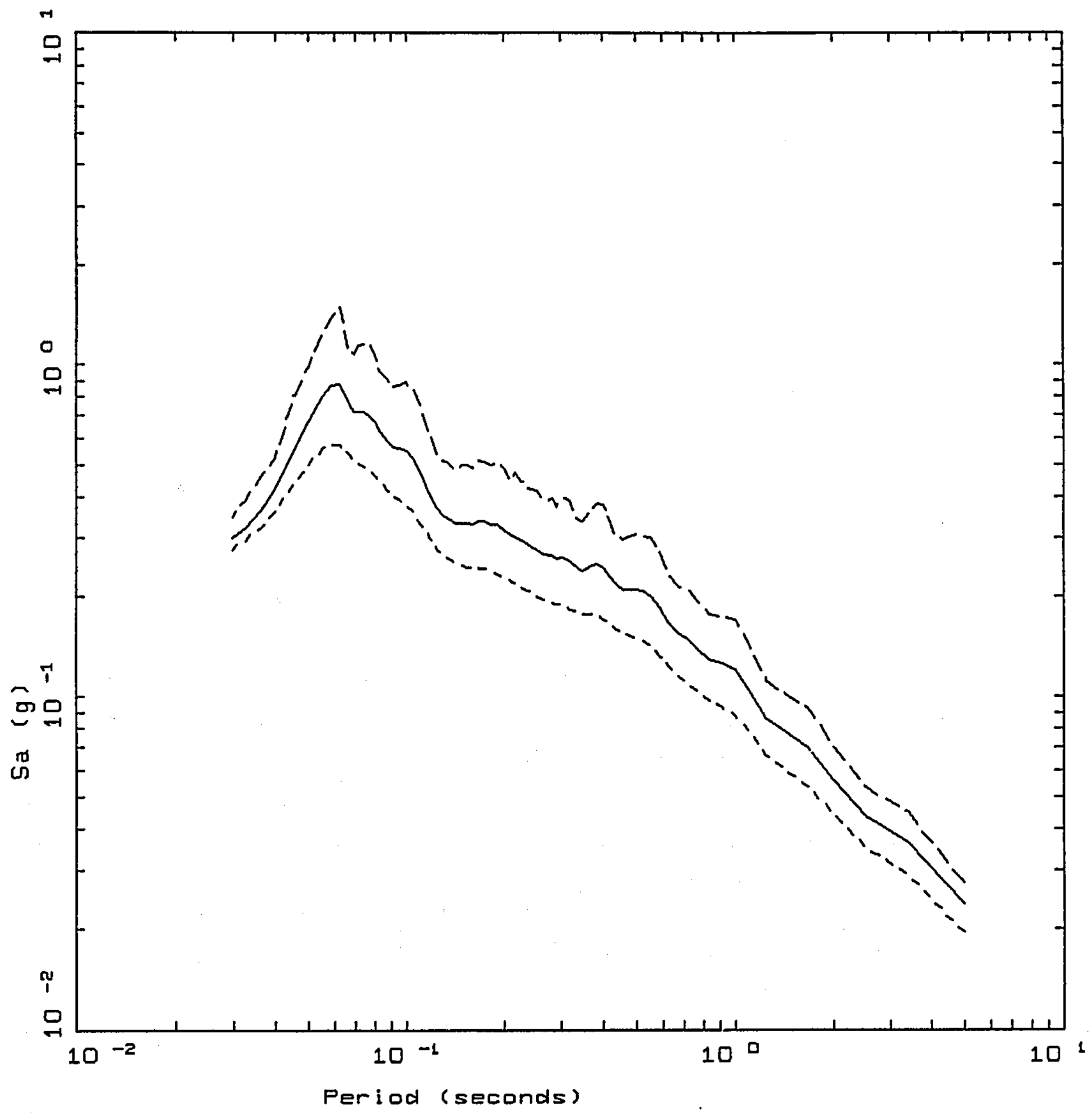
LEGEND

5 %, 84th PERCENTILE; PGA = 0.321 g

5 %, 50th PERCENTILE; PGA = 0.213 g

5 %, 16th PERCENTILE; PGA = 0.141 g

Project No. 8830035B	INEL	ANL RESPONSE SPECTRA ON SOIL 16th, 50th and 84th PERCENTILE	Figure 7
Woodward-Clyde Consultants			



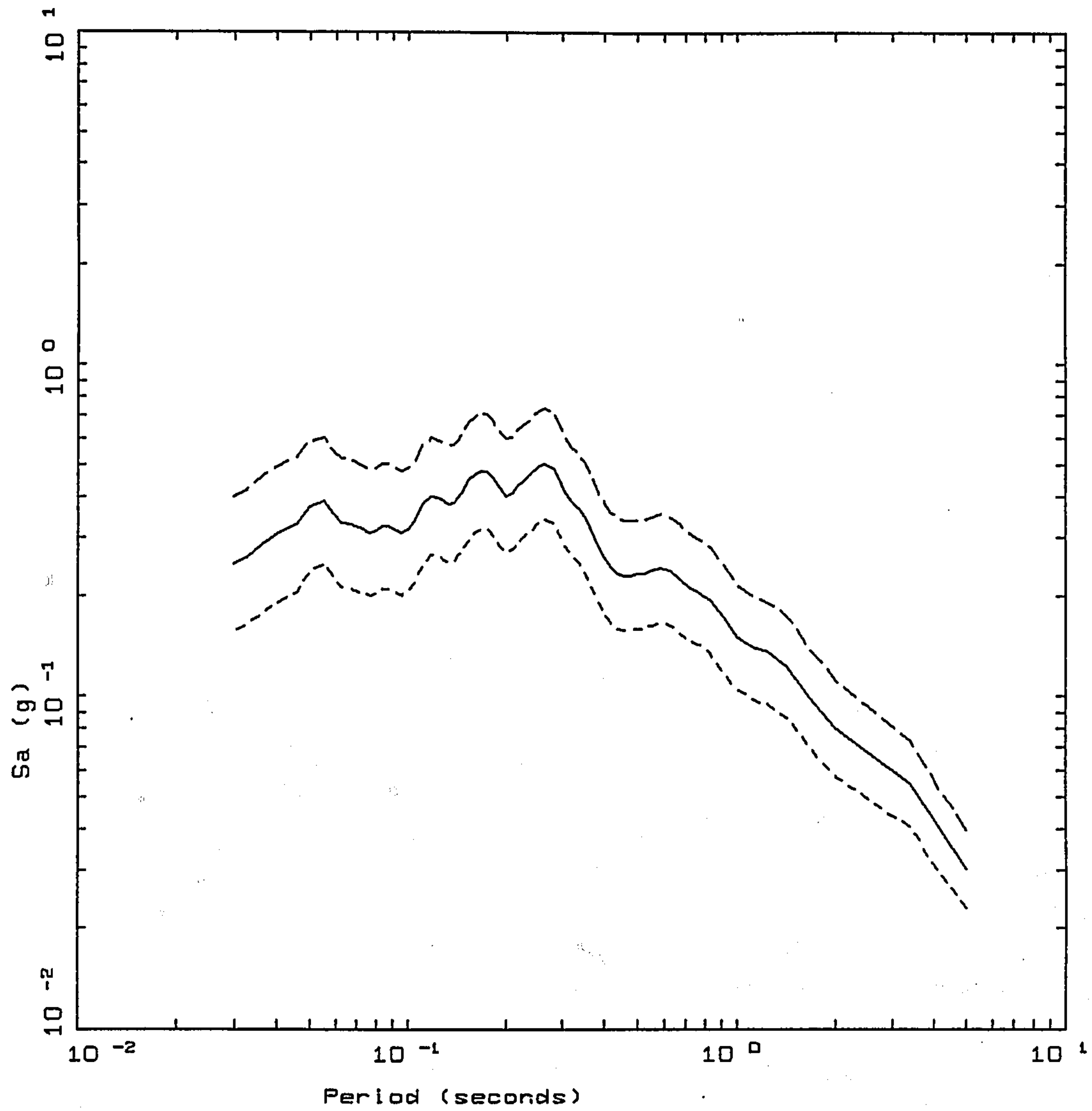
LEGEND

STANDARD MODEL, DAMPING = 5%, PGA = 0.213 g

DAMPING = 10%, PGA = 0.213 g

DAMPING = 2%, PGA = 0.213 g

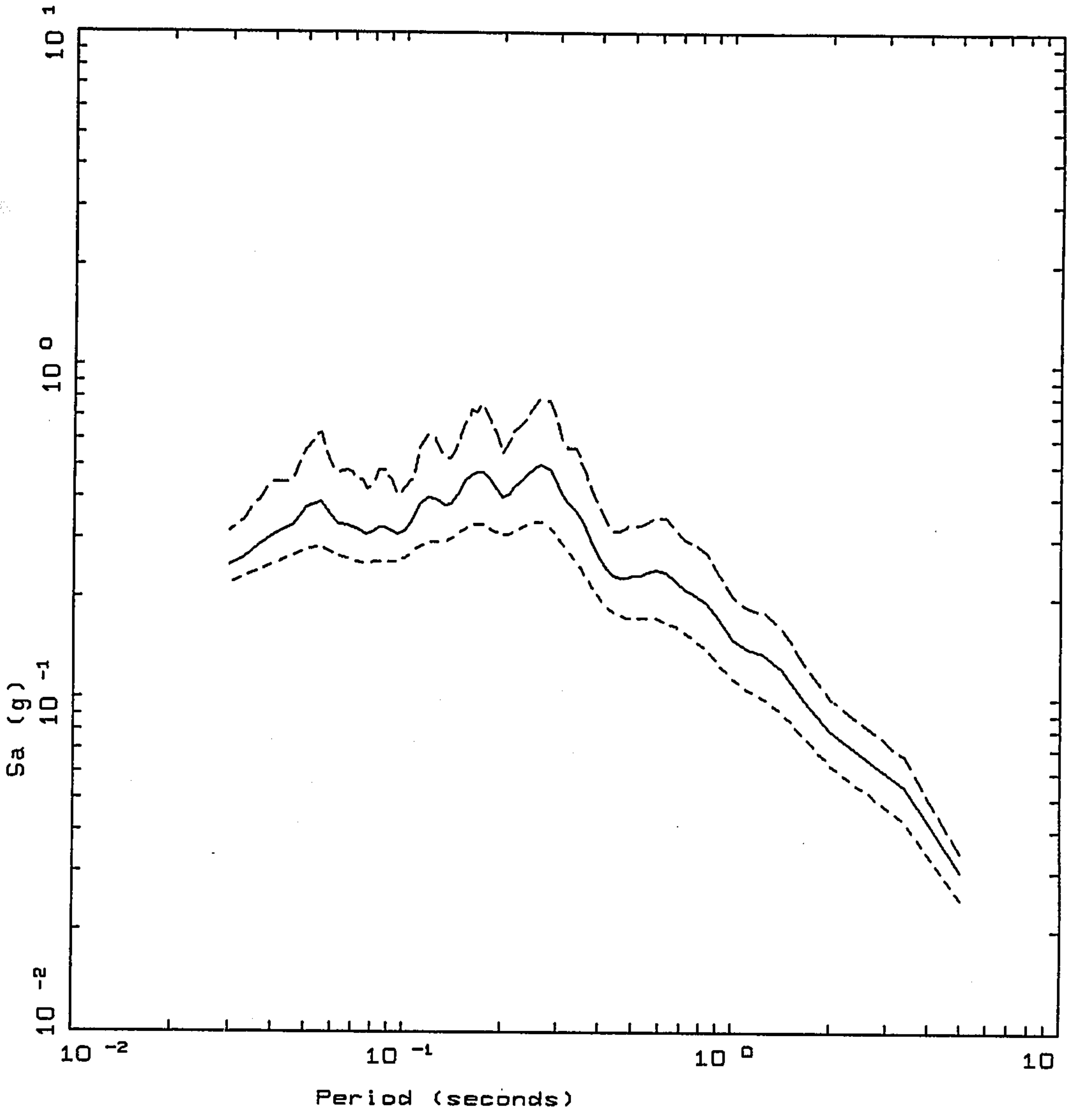
Project No. 8830095B	INEL	ANL RESPONSE SPECTRA ON SOIL VARIATION OF DAMPING	Figure 8
Woodward-Clyde Consultants			



LEGEND

-------	5 %,	84th PERCENTILE; PGA = 0.265 g
———	5 %,	50th PERCENTILE; PGA = 0.176 g
-----	5 %,	16th PERCENTILE; PGA = 0.117 g

Project No. 8830095B	INEL	ATR RESPONSE SPECTRA ON ROCK 16th, 50th and 84th PERCENTILE	Figure 9
Woodward-Clyde Consultants			



LEGEND

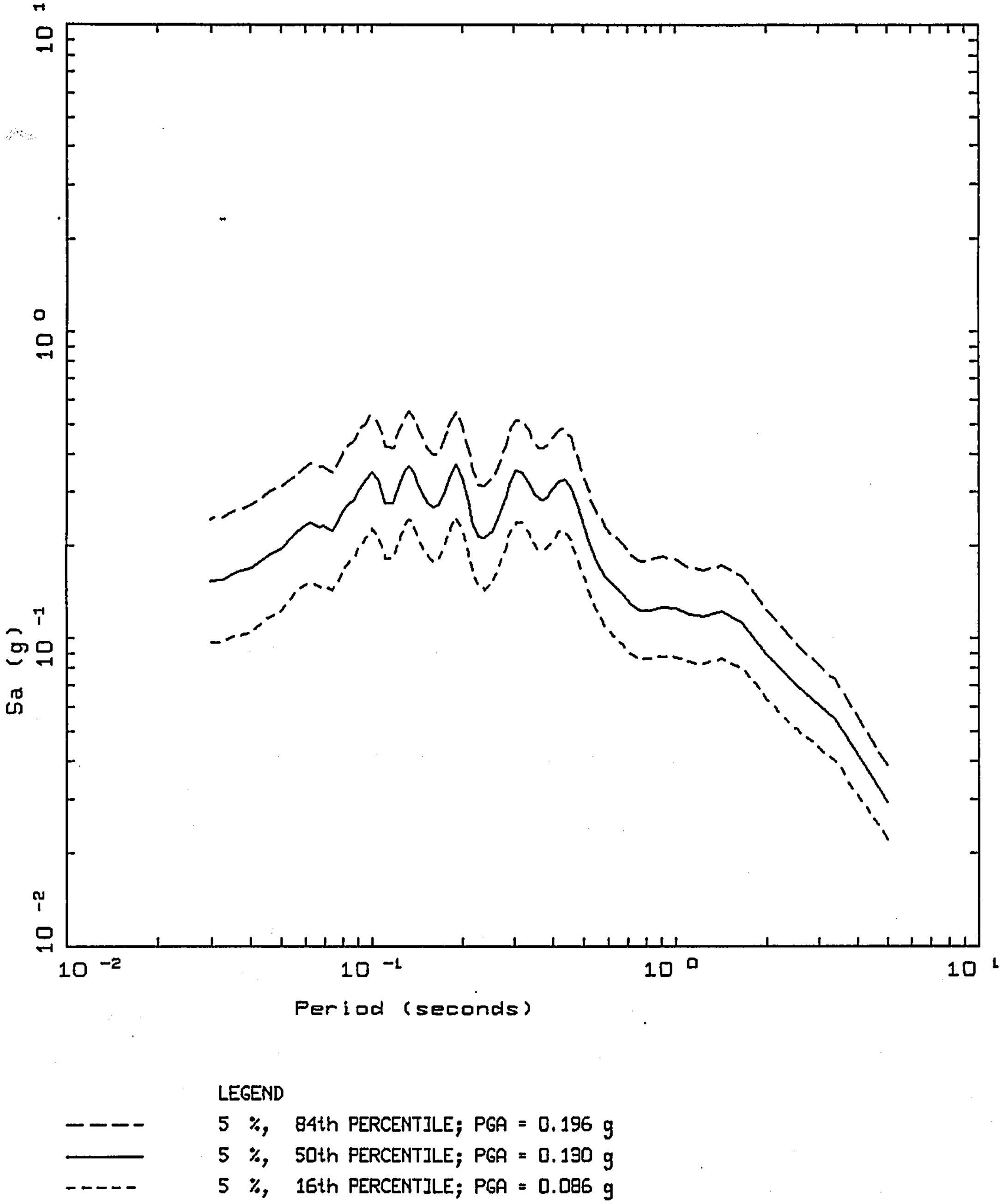
STANDARD MODEL, DAMPING = 5%, PGA = 0.176 g

DAMPING = 10%, PGA = 0.176 g

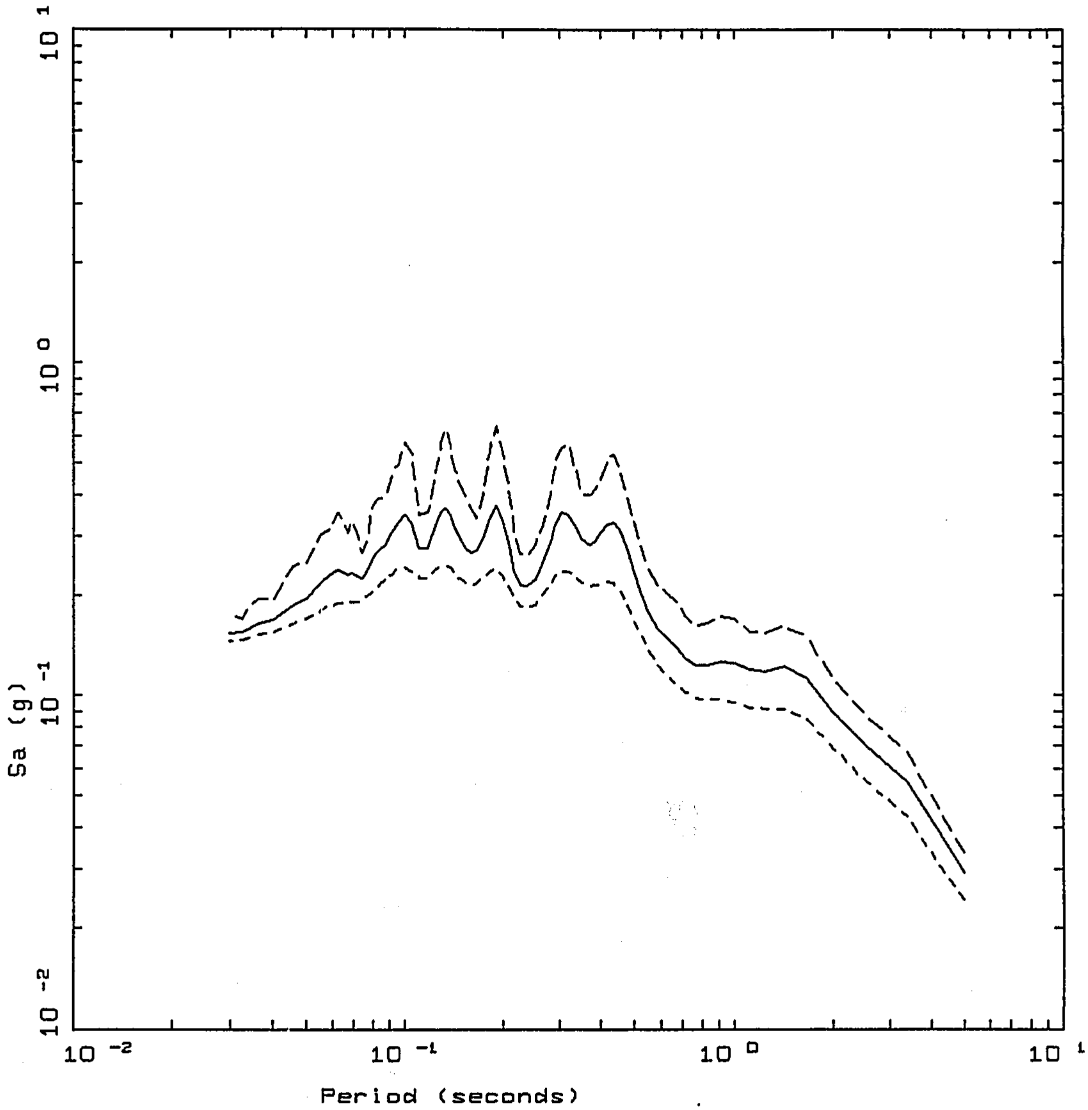
DAMPING = 2%, PGA = 0.176 g

Project No. 6830035B	INEL	ATR RESPONSE SPECTRA ON ROCK VARIATION OF DAMPING	Figure 10
Woodward-Clyde Consultants			

:rB



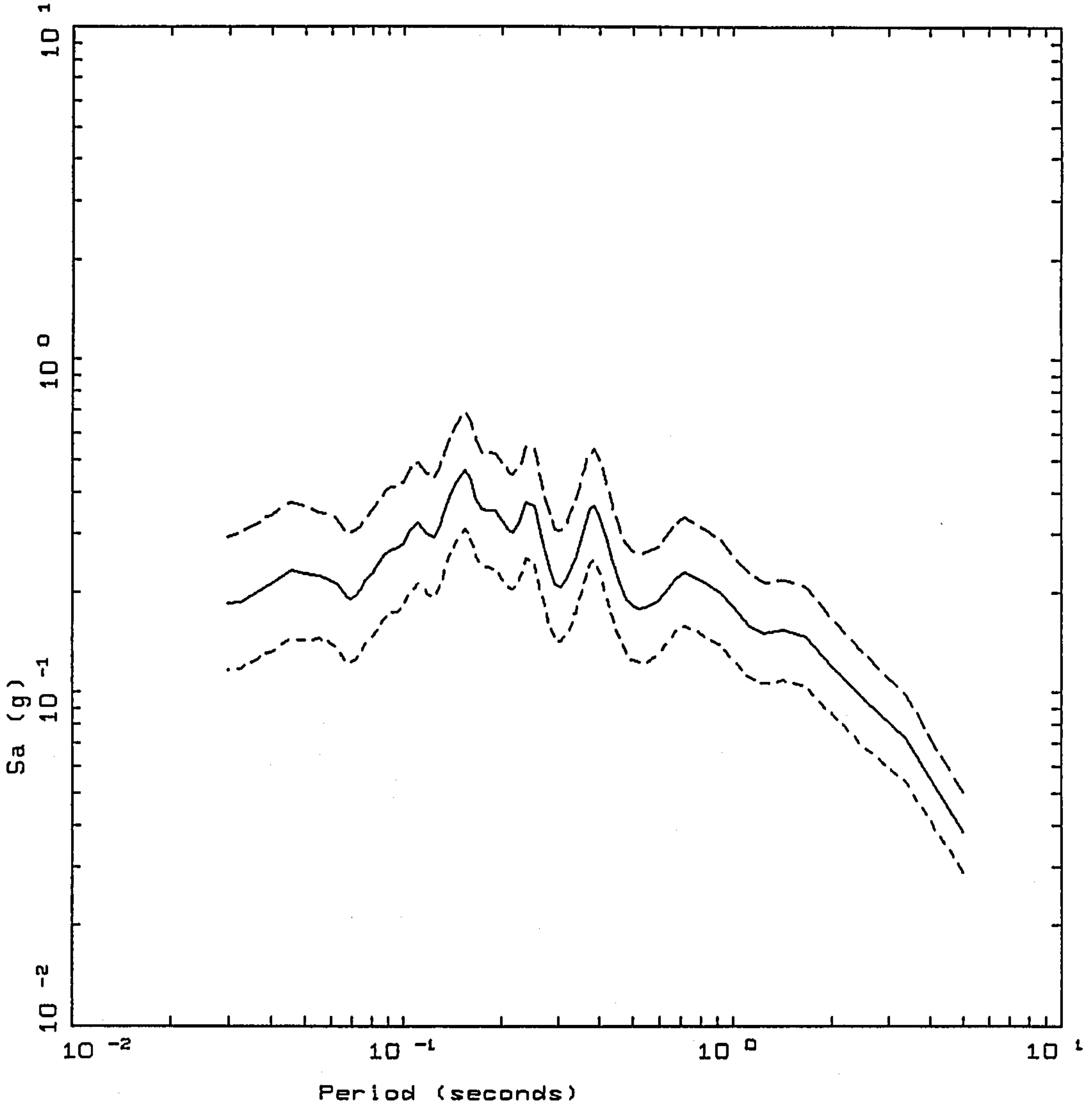
Project No. 8830035B	INEL	FPR RESPONSE SPECTRA ON ROCK 16th, 50th and 84th PERCENTILE	Figure 11
Woodward-Clyde Consultants			



LEGEND

———	STANDARD MODEL, DAMPING = 5%, PGA = 0.130 g
- - - - -	DAMPING = 10%, PGA = 0.130 g
— — — —	DAMPING = 2%, PGA = 0.130 g

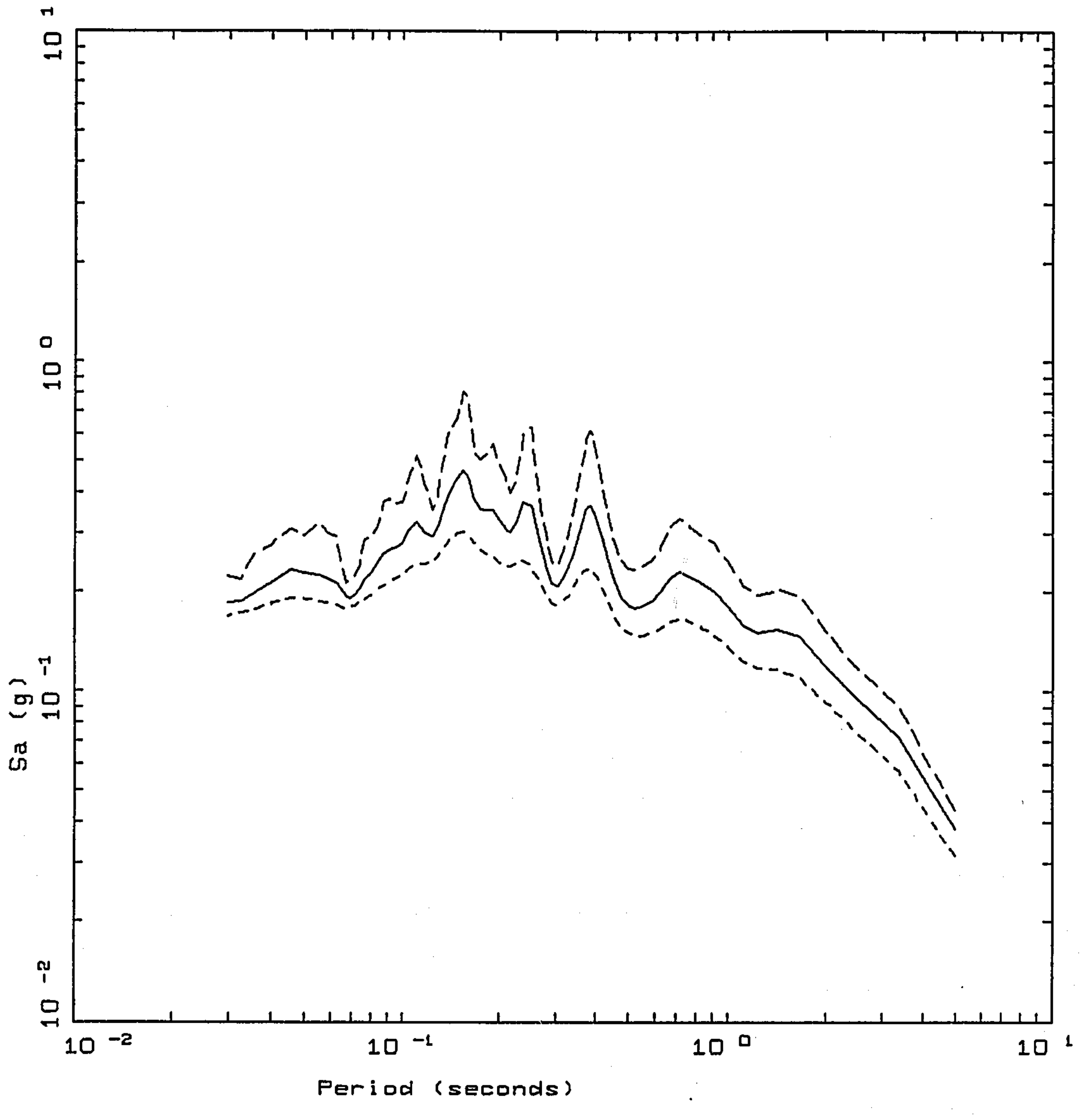
Project No. 8830035B	INEL	FPR RESPONSE SPECTRA ON ROCK VARIATION OF DAMPING	Figure 12
Woodward-Clyde Consultants			



LEGEND

— — — —	5 %, 84th PERCENTILE; PGA = 0.218 g
———	5 %, 50th PERCENTILE; PGA = 0.145 g
- - - - -	5 %, 16th PERCENTILE; PGA = 0.096 g

Project No. 6830035B	INEL	INEL1 RESPONSE SPECTRA ON ROCK 16th, 50th and 84th PERCENTILE	Figure 13
Woodward-Clyde Consultants			



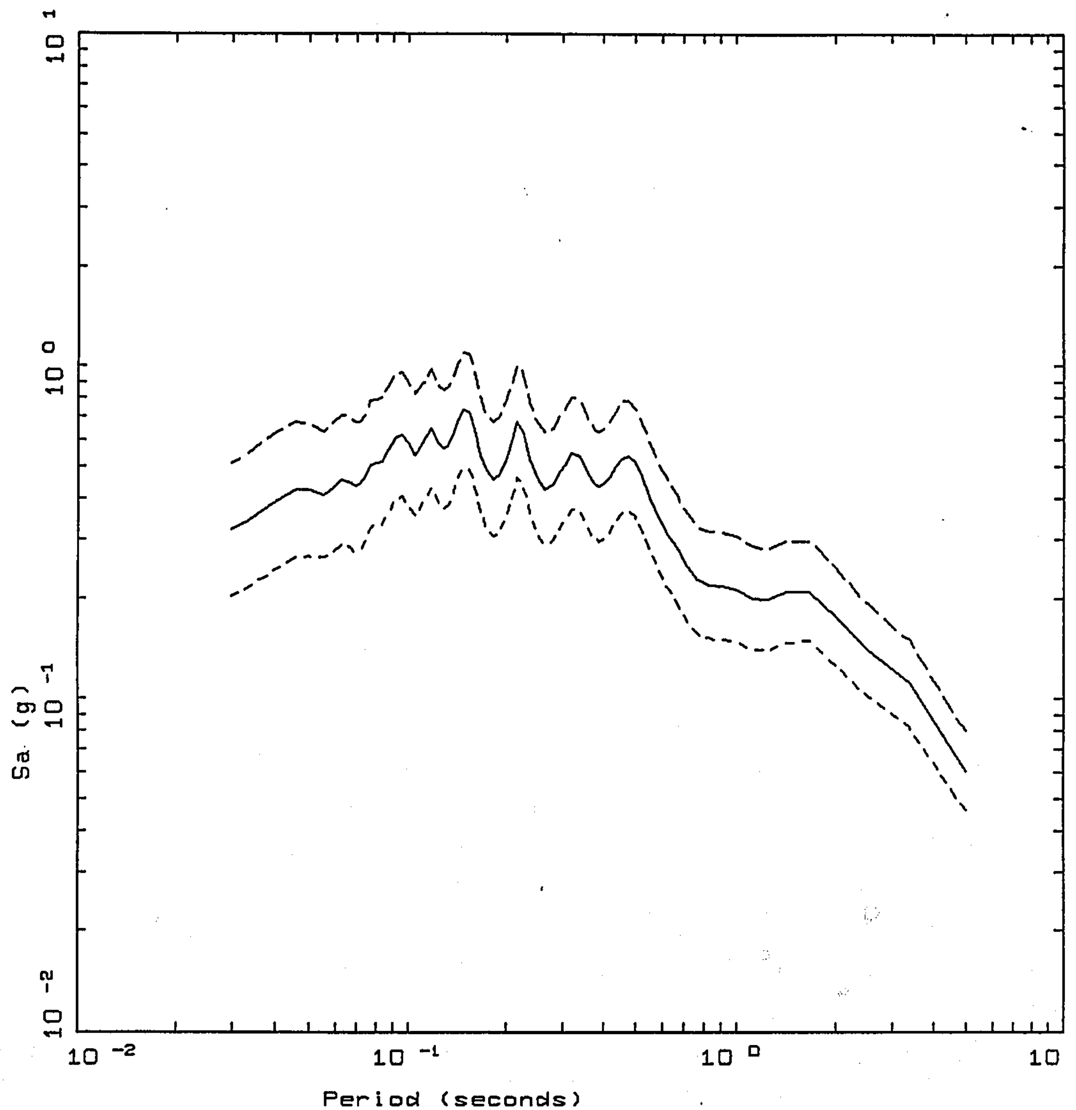
LEGEND

STANDARD MODEL, DAMPING = 5%, PGA = 0.145 g

DAMPING = 10%, PGA = 0.145 g

DAMPING = 2%, PGA = 0.145 g

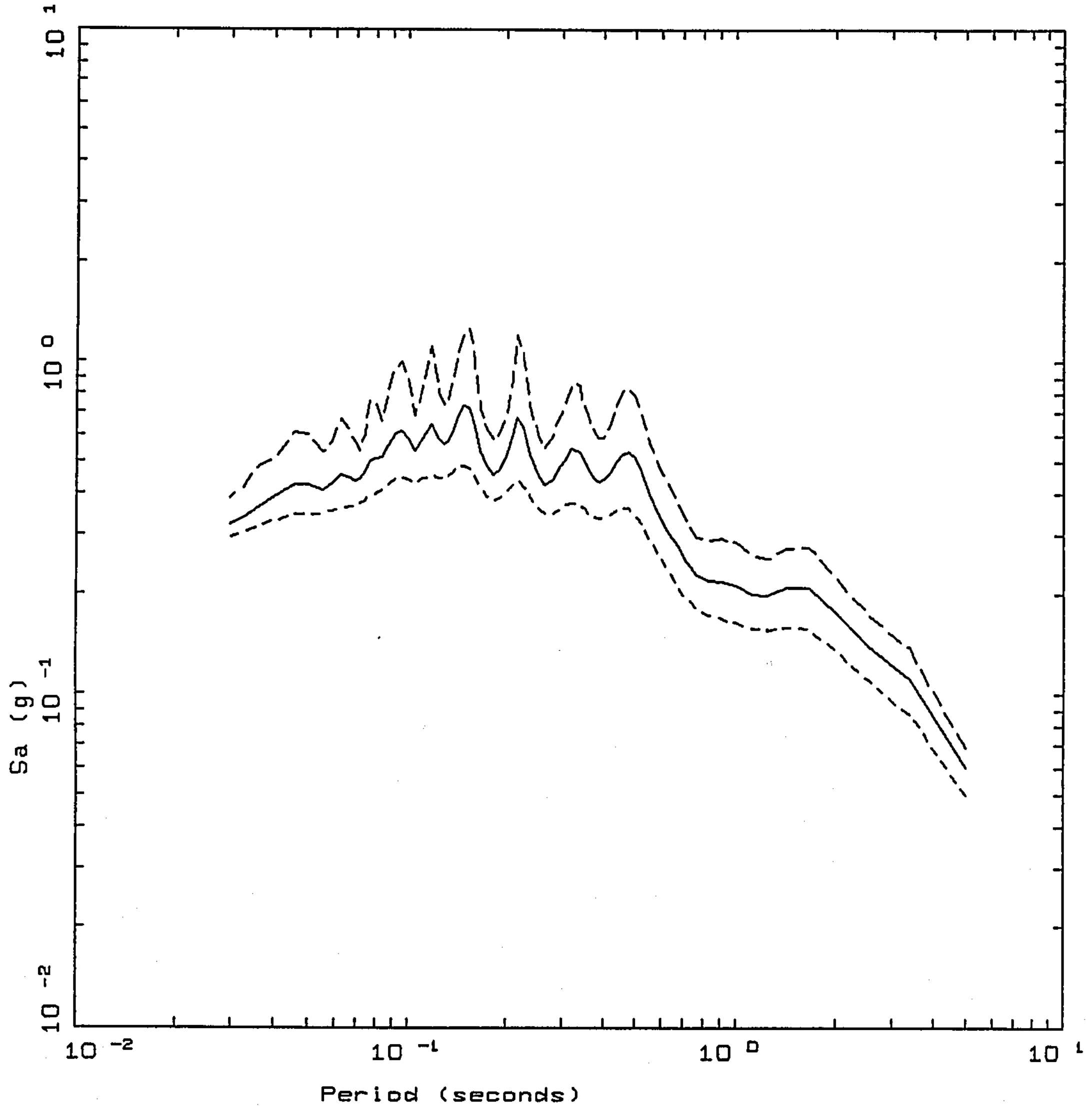
Project No. 8830035B	INEL	INEL1 RESPONSE SPECTRA ON ROCK VARIATION OF DAMPING	Figure 14
Woodward-Clyde Consultants			



LEGEND

- - - - 5 %, 84th PERCENTILE; PGA = 0.373 g
——— 5 %, 50th PERCENTILE; PGA = 0.248 g
- - - - - 5 %, 16th PERCENTILE; PGA = 0.165 g

Project No. 8830035B	INEL	LOFT RESPONSE SPECTRA ON ROCK 16th, 50th and 84th PERCENTILE	Figure 15
Woodward-Clyde Consultants			



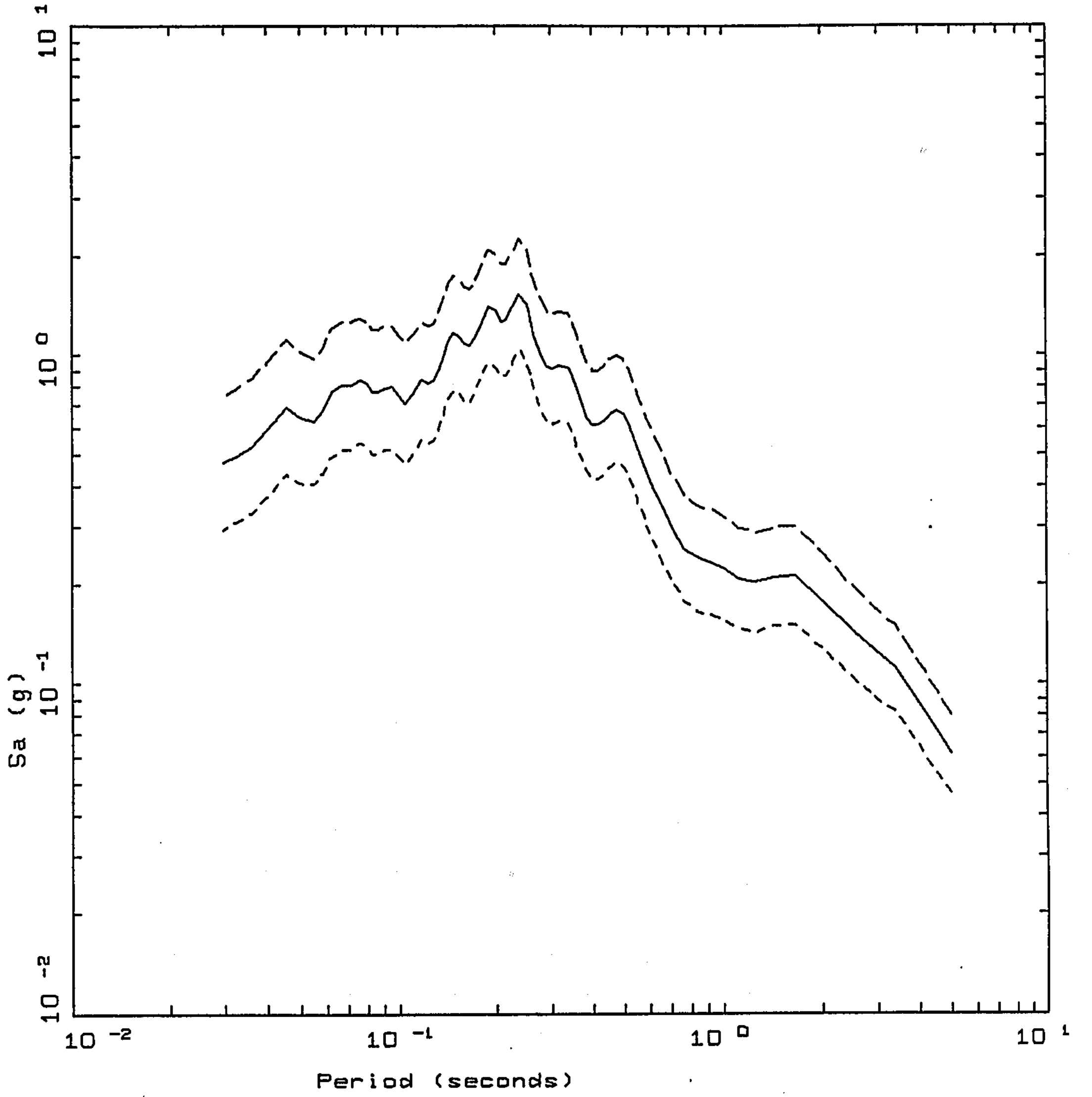
LEGEND

STANDARD MODEL, DAMPING = 5%, PGA = 0.248 g

DAMPING = 10%, PGA = 0.248 g

DAMPING = 2%, PGA = 0.248 g

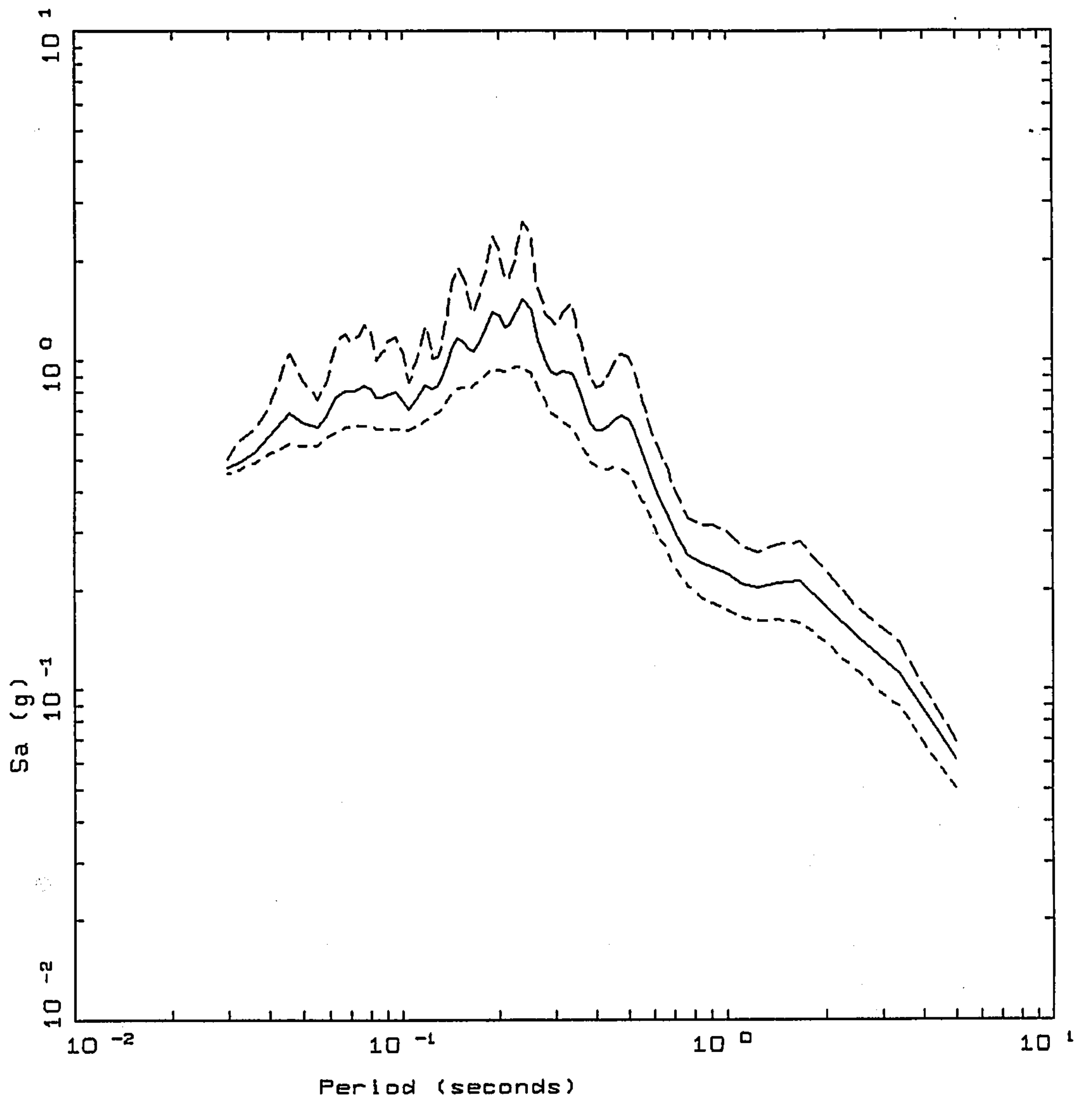
Project No. 8830035B	INEL	LOFT RESPONSE SPECTRA ON ROCK VARIATION OF DAMPING	Figure 16
Woodward-Clyde Consultants			



LEGEND

– – – –	5 %, 84th PERCENTILE; PGA = 0.608 g
———	5 %, 50th PERCENTILE; PGA = 0.404 g
- - - - -	5 %, 16th PERCENTILE; PGA = 0.268 g

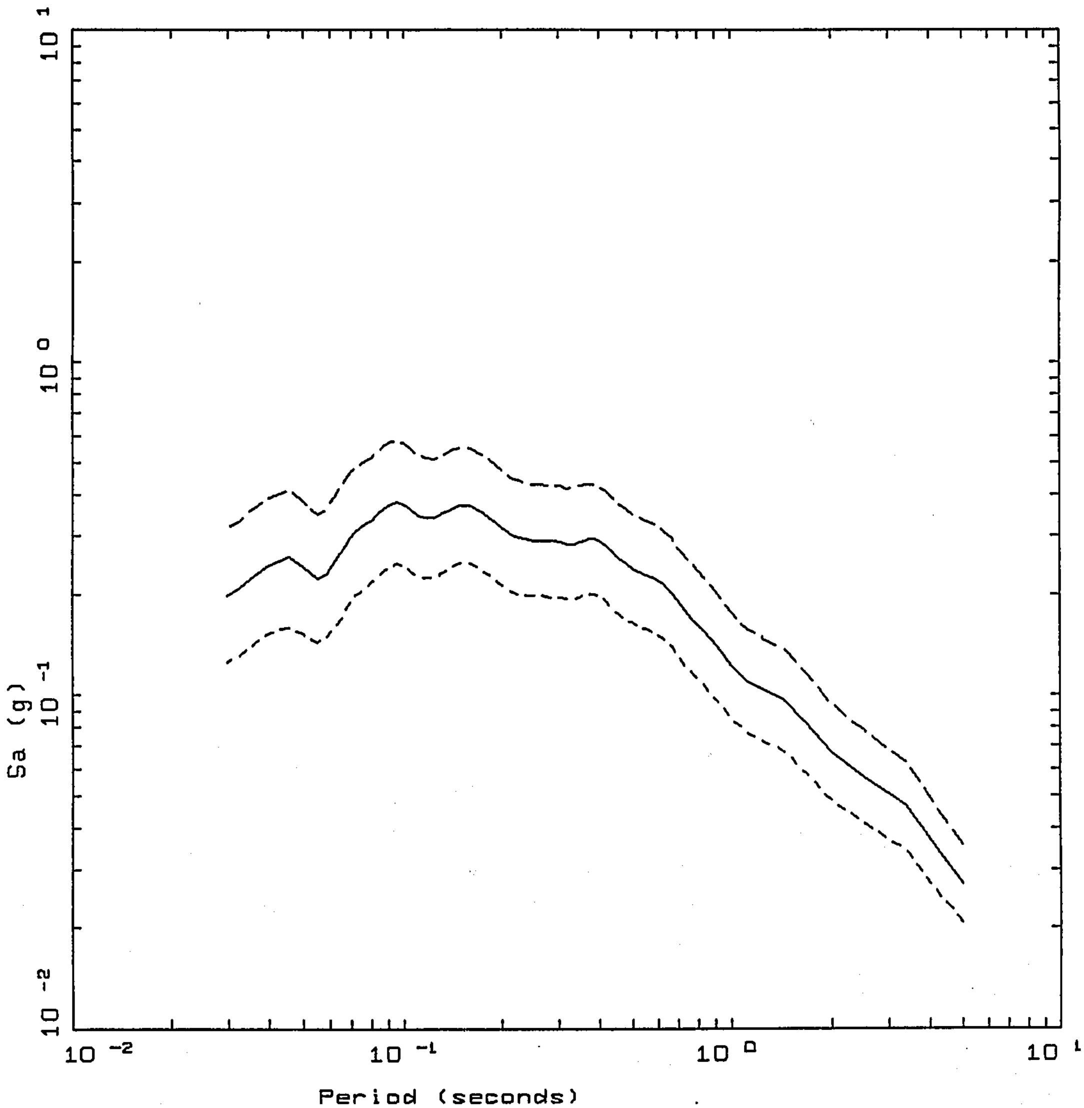
Project No. 8830035B	INEL	LOFT RESPONSE SPECTRA ON SOIL 16th, 50th and 84th PERCENTILE	Figure 17
Woodward-Clyde Consultants			



LEGEND

- ——— STANDARD MODEL, DAMPING = 5%, PGA = 0.404 g
- - - - - - DAMPING = 10%, PGA = 0.404 g
- — — — DAMPING = 2%, PGA = 0.404 g

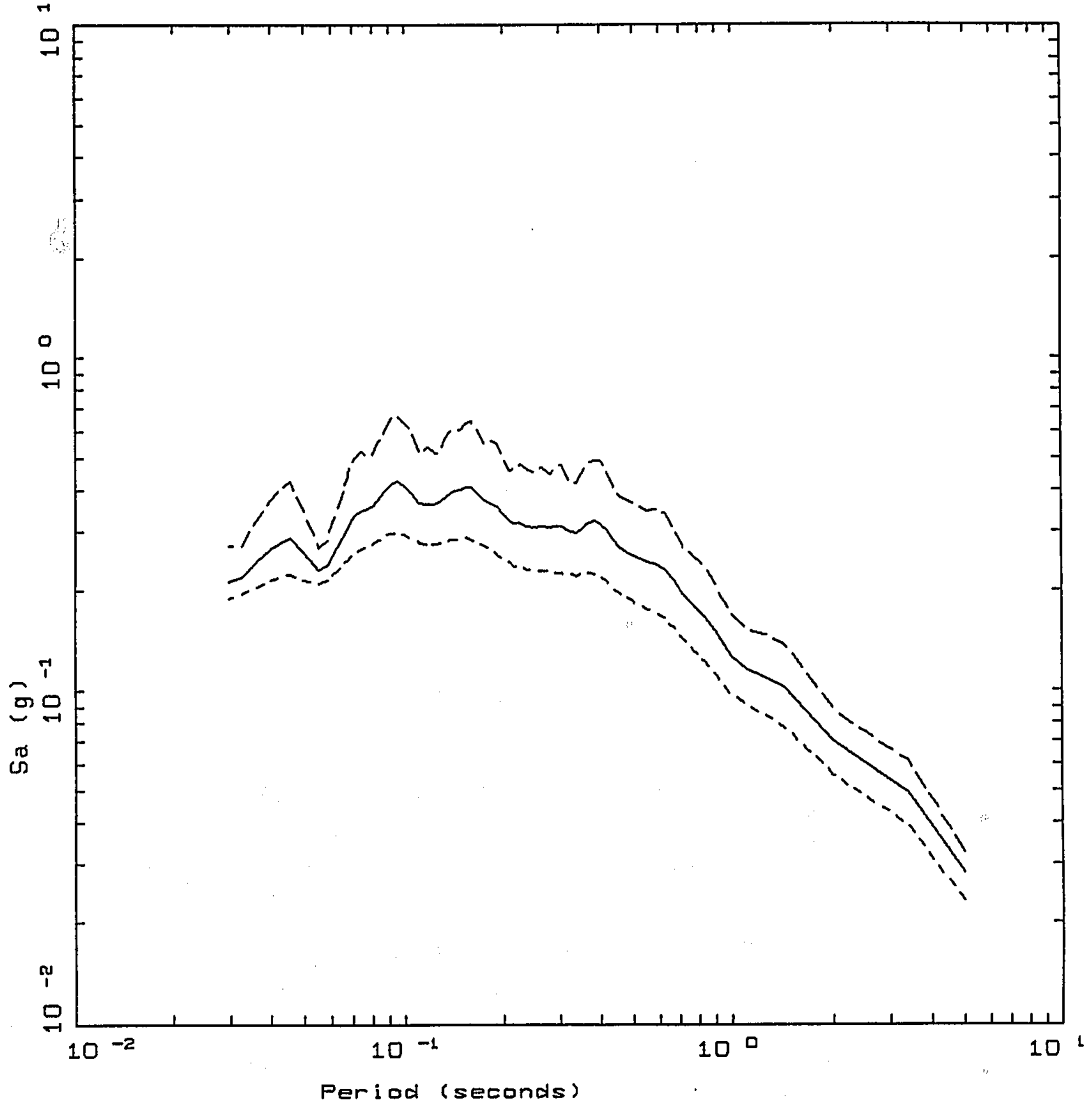
Project No. 8830035B	INEL	LOFT RESPONSE SPECTRA ON SOIL VARIATION OF DAMPING	Figure 18
Woodward-Clyde Consultants			



LEGEND

– – – –	5 %, 84th PERCENTILE; PGA = 0.219 g
———	5 %, 50th PERCENTILE; PGA = 0.145 g
- - - - -	5 %, 16th PERCENTILE; PGA = 0.096 g

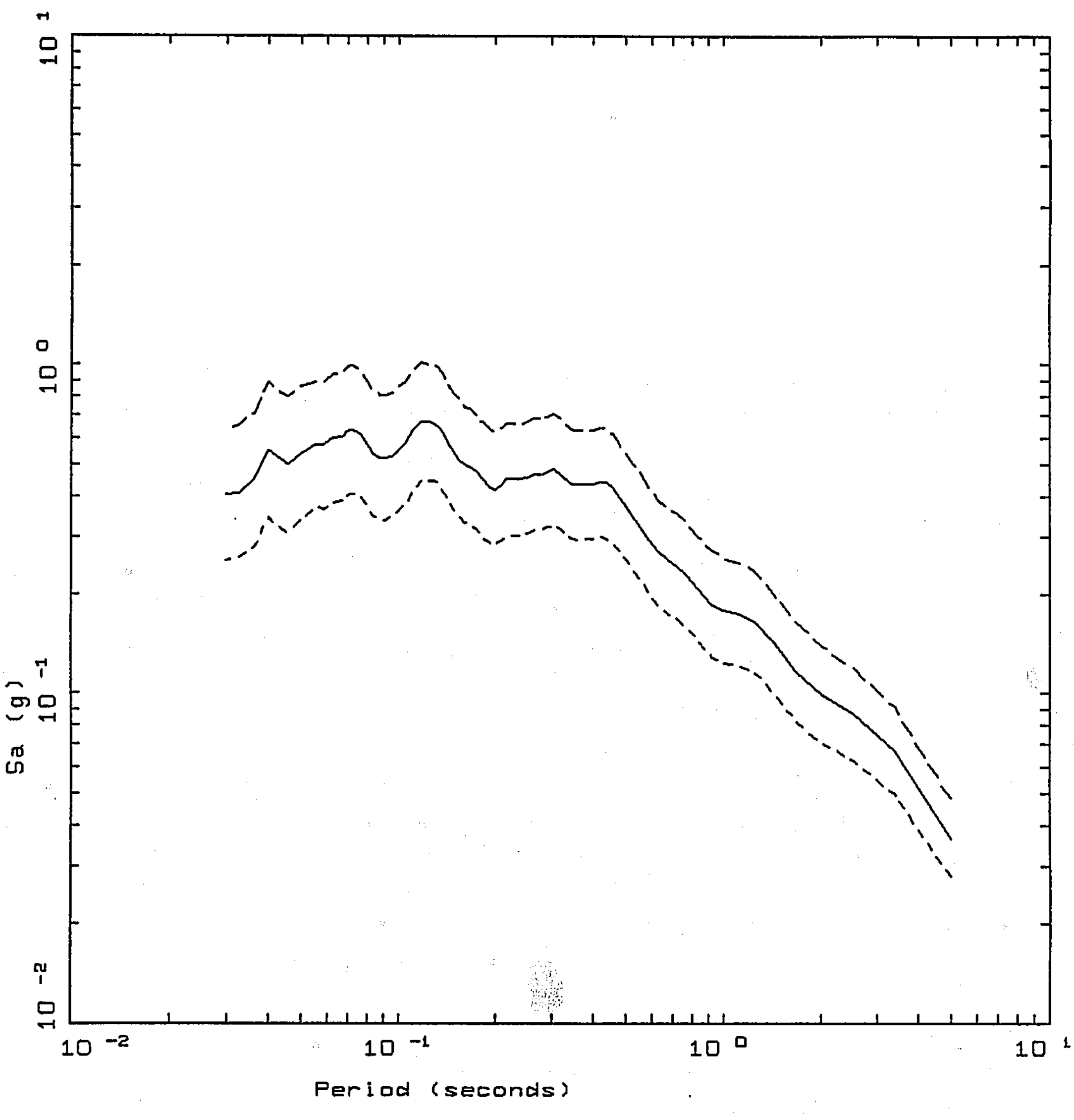
Project No. 8830035B	INEL	NPR RESPONSE SPECTRA ON ROCK 16th, 50th and 84th PERCENTILE	Figure 19
Woodward-Clyde Consultants			



LEGEND

———	STANDARD MODEL, DAMPING = 5%, PGA = 0.155 g
- - - - -	DAMPING = 10%, PGA = 0.155 g
— — — —	DAMPING = 2%, PGA = 0.155 g

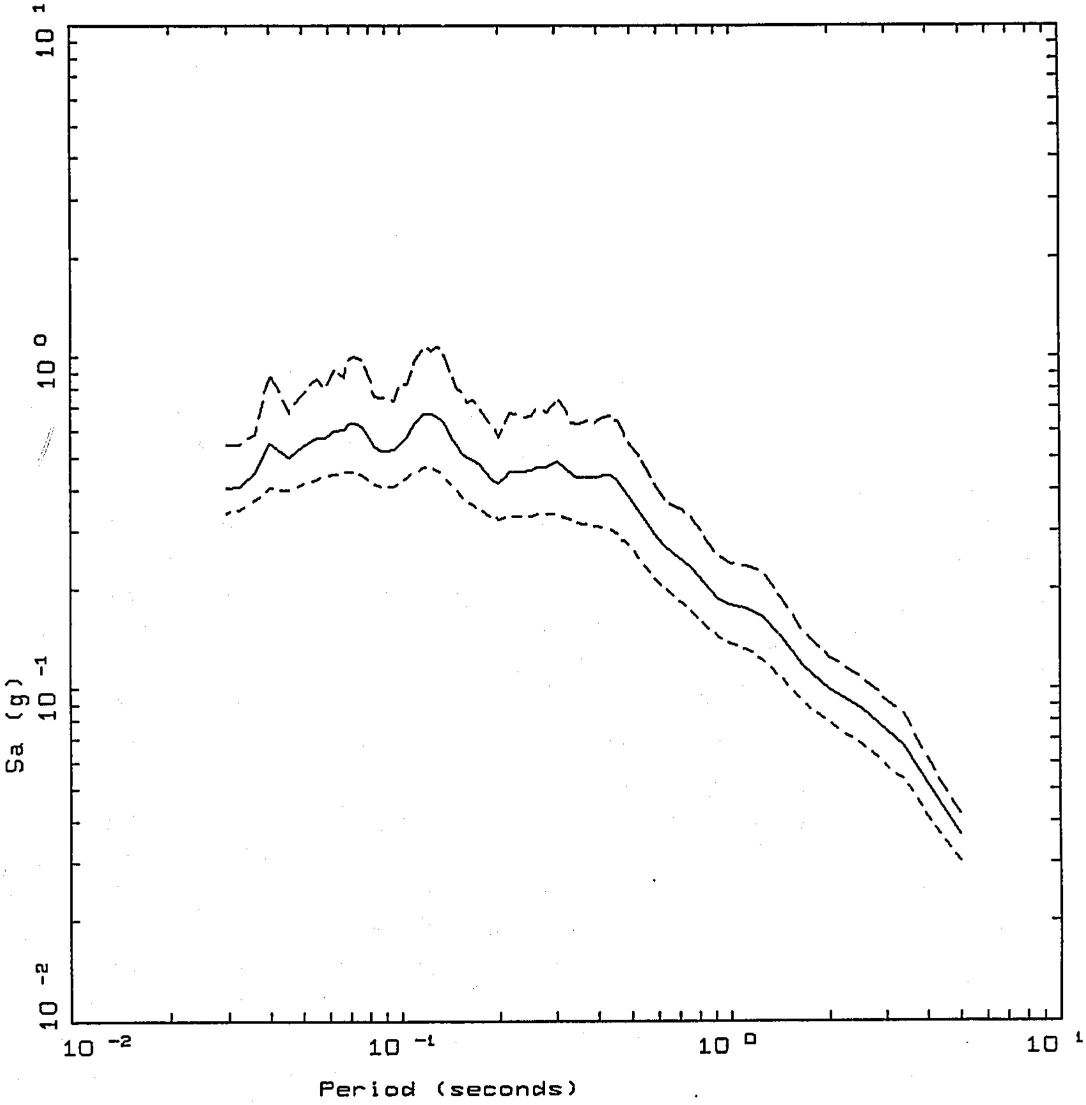
Project No. 8830035B	INEL	NPR RESPONSE SPECTRA ON ROCK VARIATION OF DAMPING	Figure 20
Woodward-Clyde Consultants			



LEGEND

— — — —	5 %,	84th PERCENTILE; PGA = 0.372 g
————	5 %,	50th PERCENTILE; PGA = 0.247 g
- - - - -	5 %,	16th PERCENTILE; PGA = 0.164 g

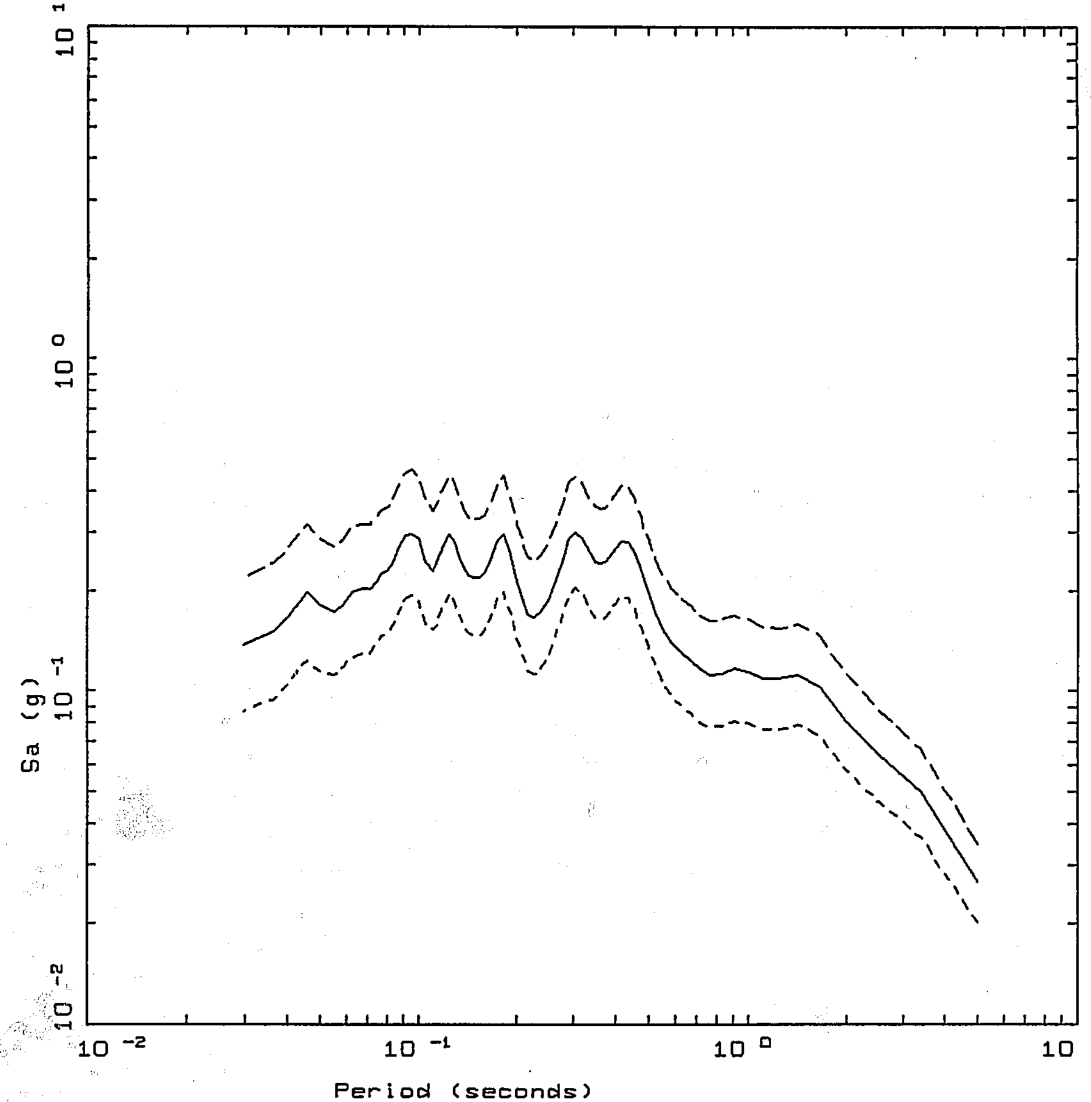
Project No. 8830035B	INEL	NRF RESPONSE SPECTRA ON ROCK 16th, 50th and 84th PERCENTILE	Figure 21
Woodward-Clyde Consultants			



LEGEND

————	STANDARD MODEL, DAMPING = 5%, PGA = 0.247 g
- - - - -	DAMPING = 10%, PGA = 0.247 g
— — — —	DAMPING = 2%, PGA = 0.247 g

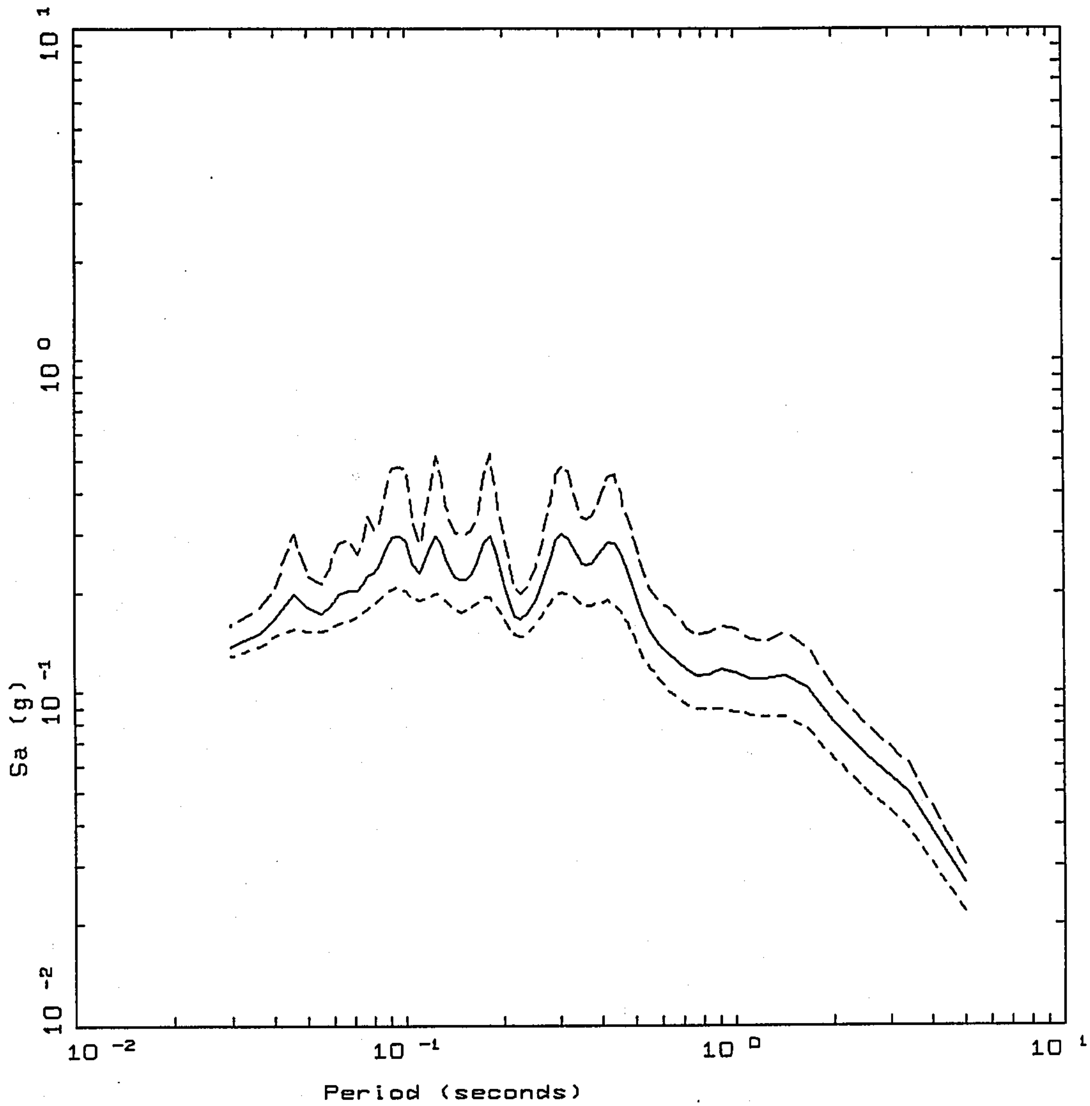
Project No. 8830035B	INEL	NRF RESPONSE SPECTRA ON ROCK VARIATION OF DAMPING	Figure 22
Woodward-Clyde Consultants			



LEGEND

— — — —	5 %,	84th PERCENTILE; PGA = 0.169 g
————	5 %,	50th PERCENTILE; PGA = 0.112 g
- - - - -	5 %,	16th PERCENTILE; PGA = 0.074 g

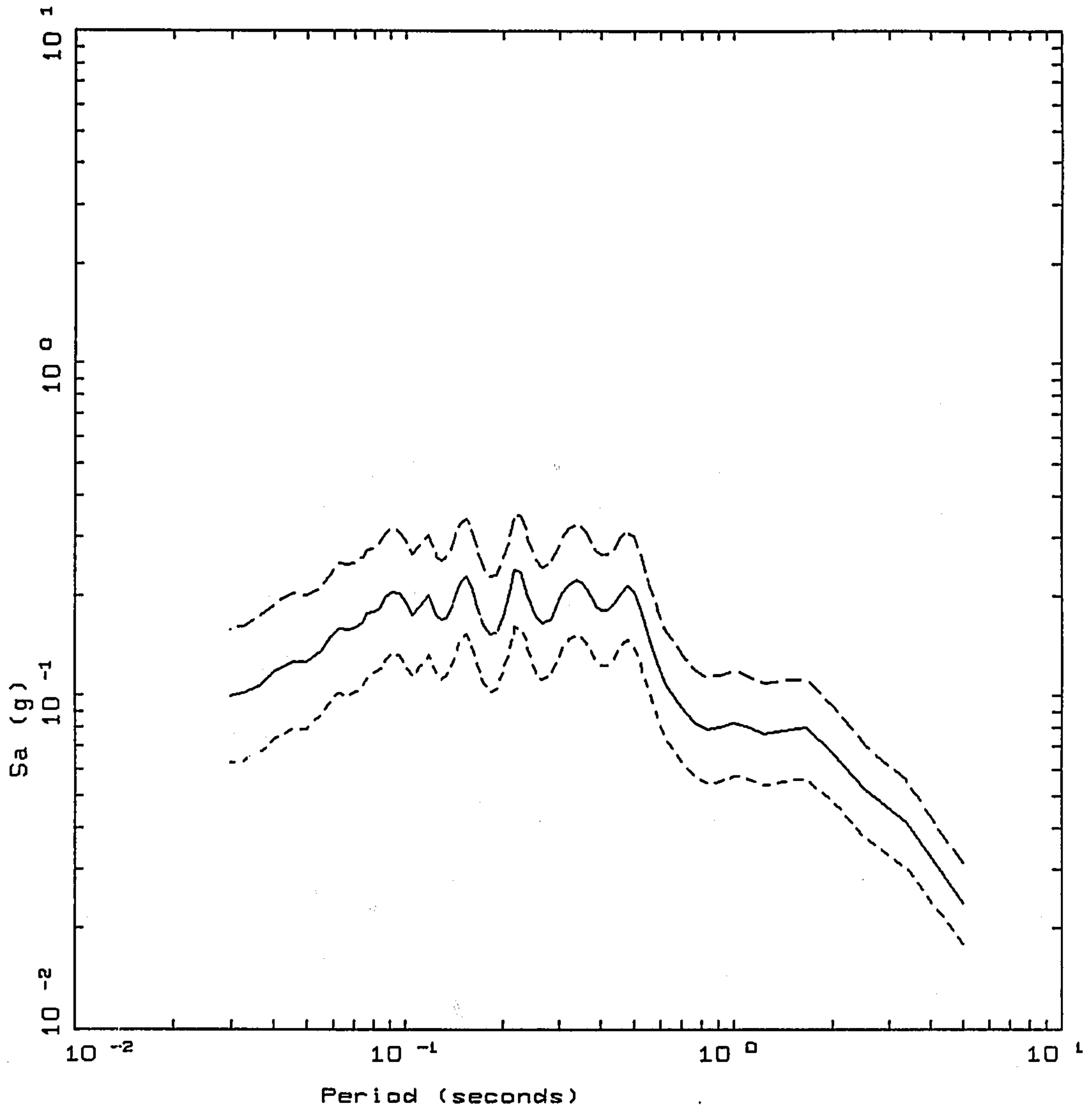
Project No. 8830035B / INEL / Woodward-Clyde Consultants	PBF RESPONSE SPECTRA ON ROCK 16th, 50th and 84th PERCENTILE	Figure 23



LEGEND

———	STANDARD MODEL, DAMPING = 5%, PGA = 0.112 g
- - - - -	DAMPING = 10%, PGA = 0.112 g
— — — —	DAMPING = 2%, PGA = 0.112 g

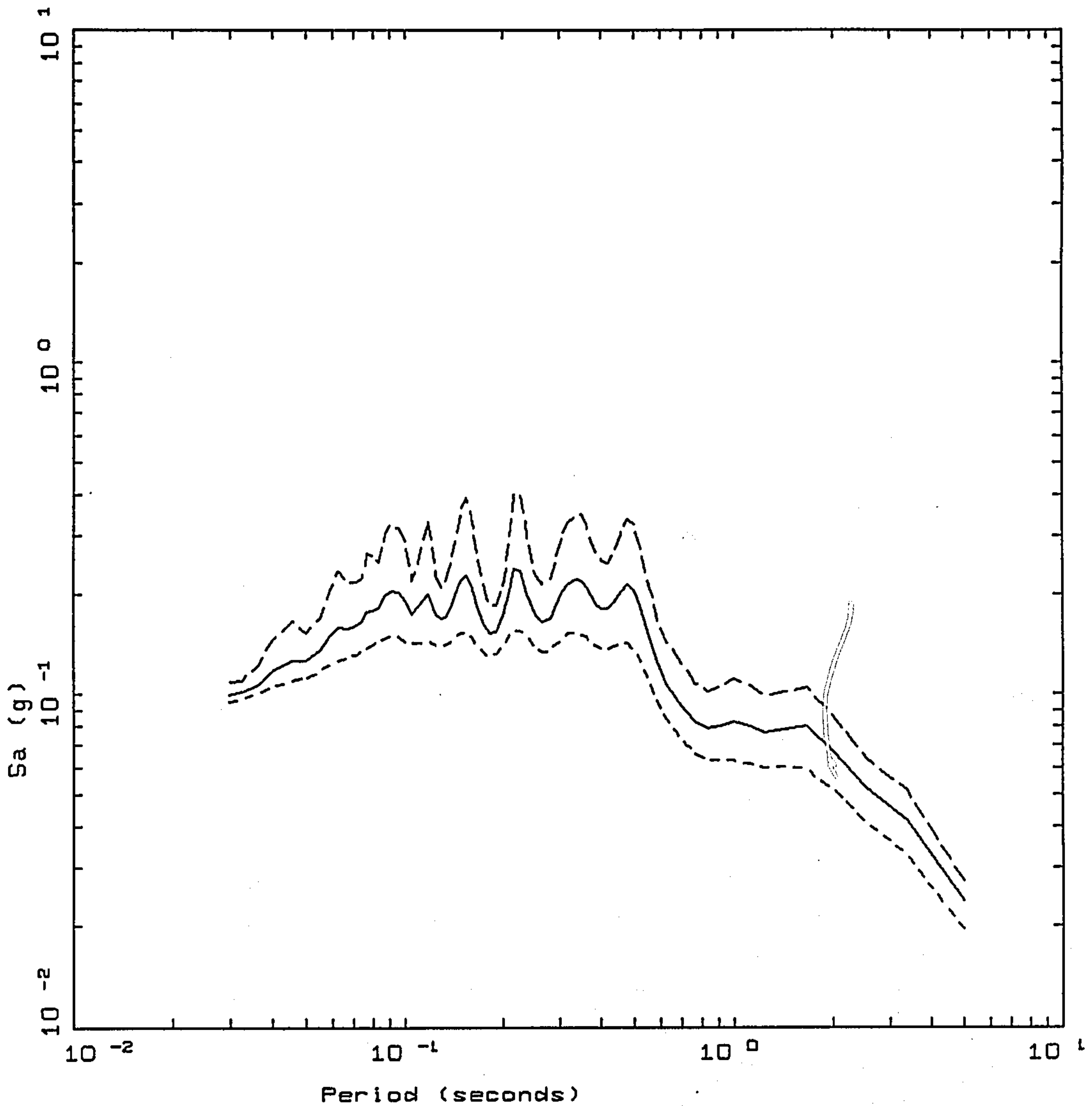
Project No. 8830035B	INEL	PBF RESPONSE SPECTRA ON ROCK VARIATION OF DAMPING	Figure 24
Woodward-Clyde Consultants			



LEGEND

– – – –	5 %,	84th PERCENTILE; PGA = 0.130 g
———	5 %,	50th PERCENTILE; PGA = 0.086 g
- - - - -	5 %,	16th PERCENTILE; PGA = 0.057 g

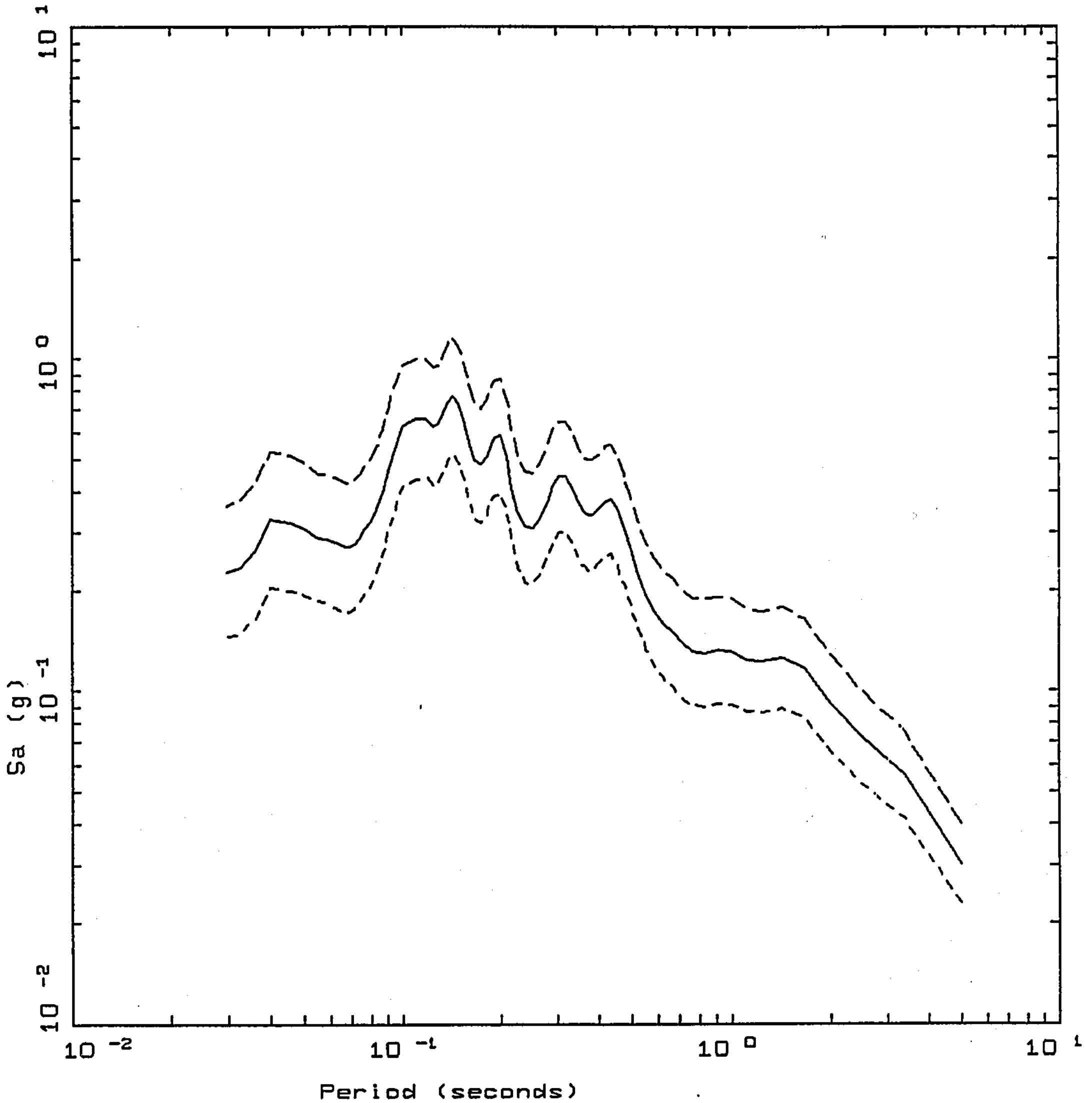
Project No. 8830035B	INEL	RWMC RESPONSE SPECTRA ON ROCK 16th, 50th and 84th PERCENTILE	Figure 25
Woodward-Clyde Consultants			



LEGEND

———	STANDARD MODEL, DAMPING = 5%, PGA = 0.086 g
- - - - -	DAMPING = 10%, PGA = 0.086 g
— — — —	DAMPING = 2%, PGA = 0.086 g

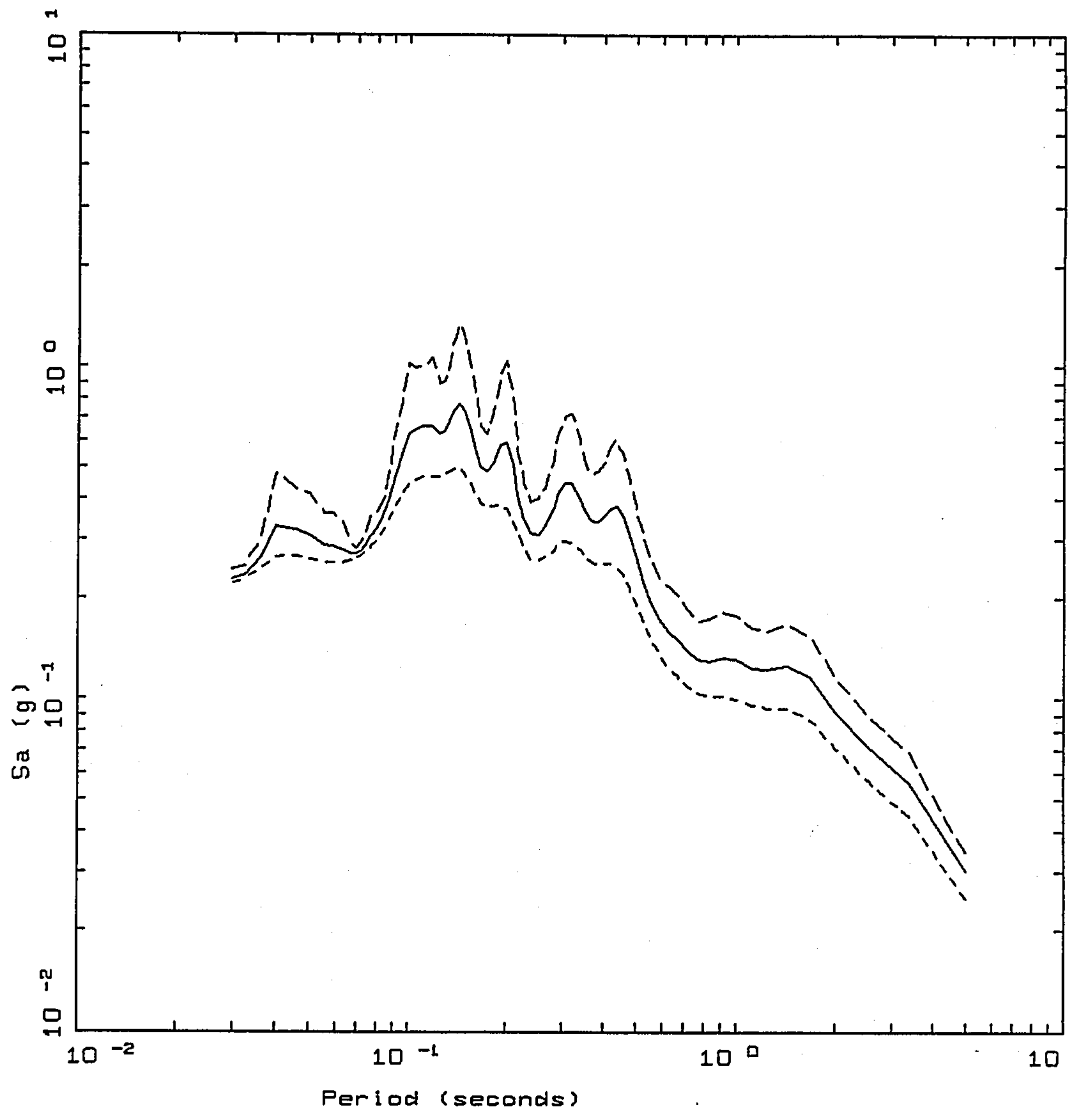
Project No. 8830035B	INEL	RWMC RESPONSE SPECTRA ON ROCK VARIATION OF DAMPING	Figure 26
Woodward-Clyde Consultants			



LEGEND

– – – –	5 %,	84th PERCENTILE; PGA = 0.297 g
———	5 %,	50th PERCENTILE; PGA = 0.197 g
- - - - -	5 %,	16th PERCENTILE; PGA = 0.131 g

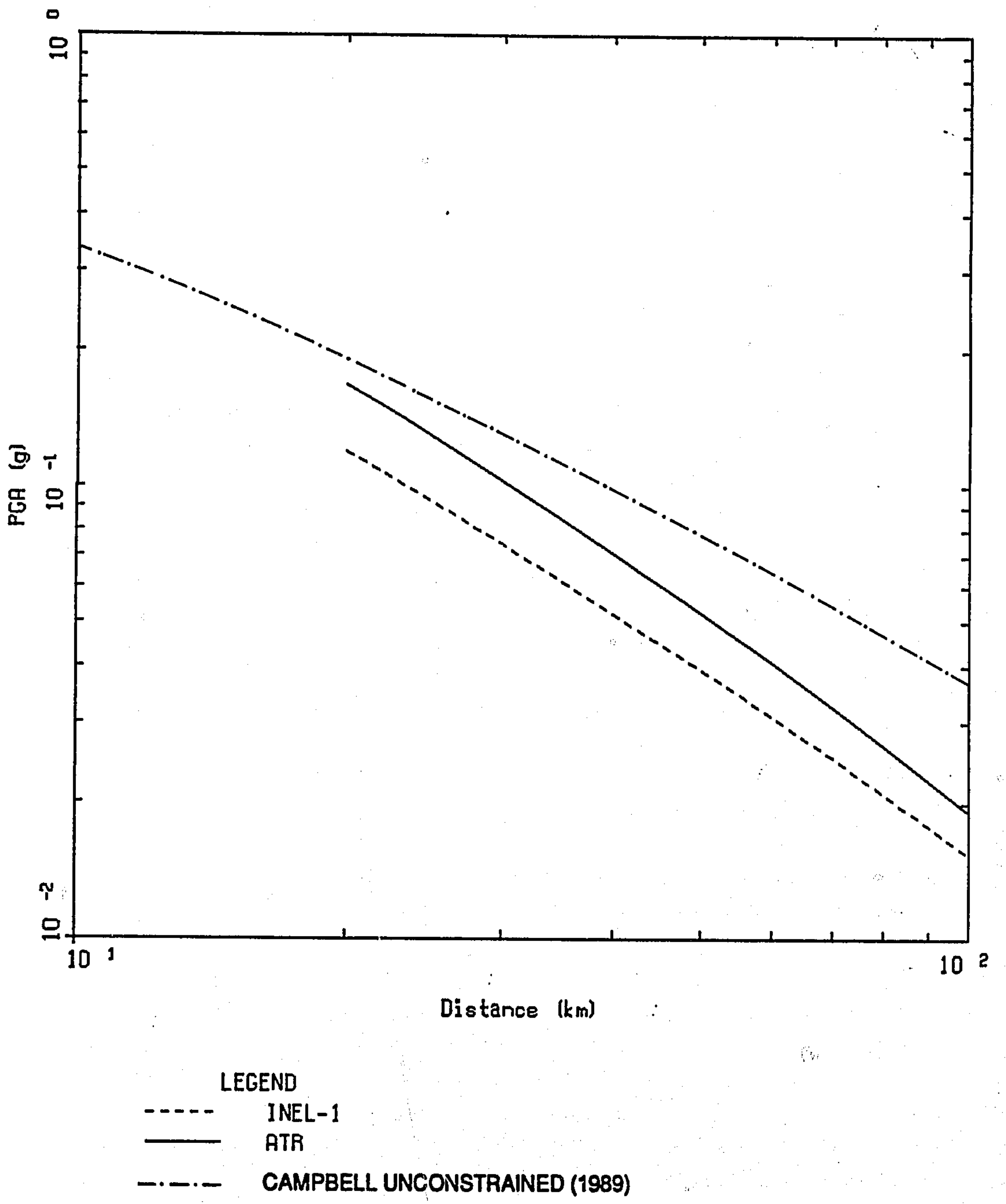
Project No. 8830035B	INEL	SIS RESPONSE SPECTRA ON SOIL 16th, 50th and 84th PERCENTILE	Figure 27
Woodward-Clyde Consultants			



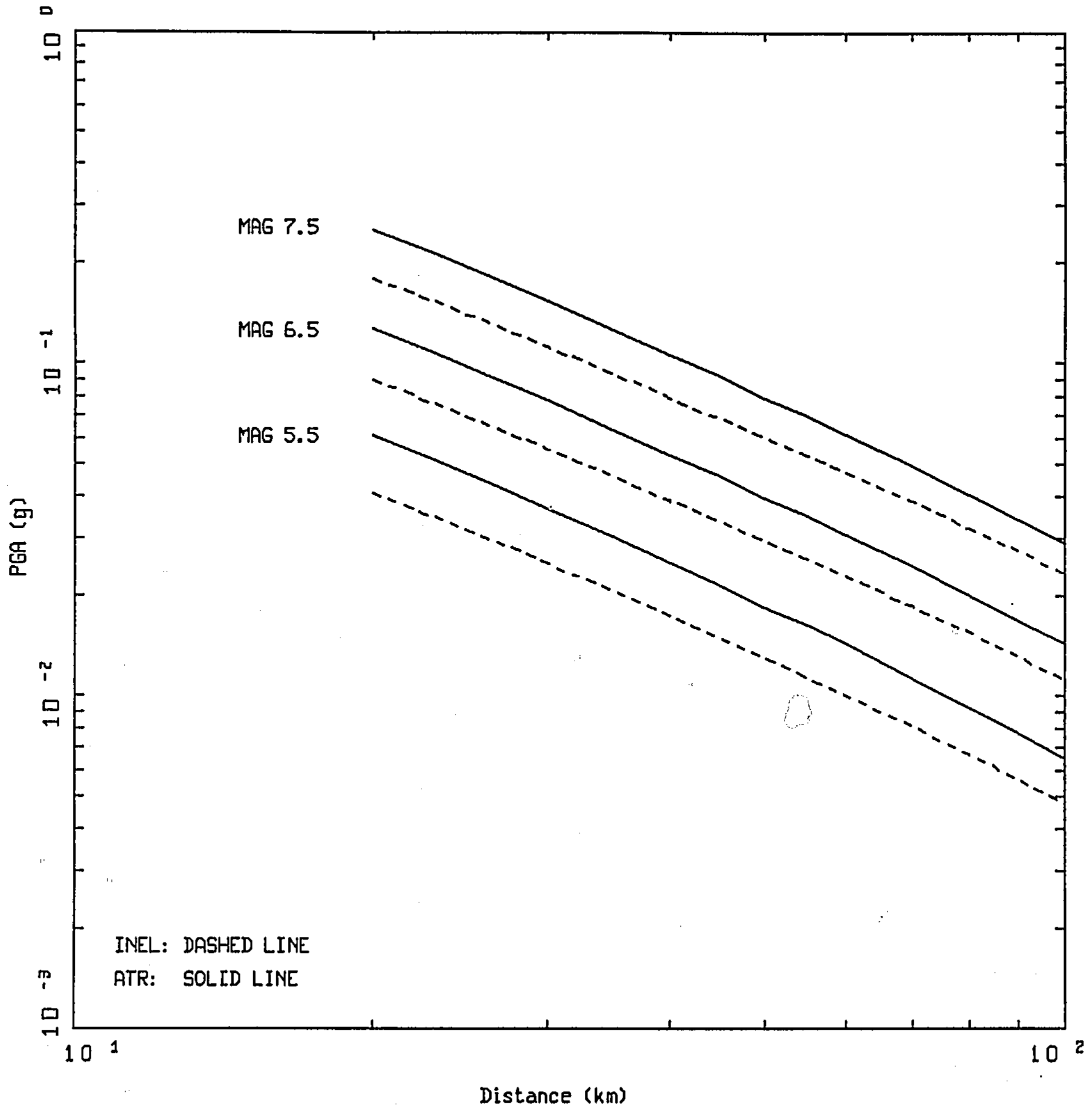
LEGEND

————	STANDARD MODEL, DAMPING = 5%, PGA = 0.197 g
- - - - -	DAMPING = 10%, PGA = 0.197 g
— — — —	DAMPING = 2%, PGA = 0.197 g

Project No. 8830035B	INEL	SIS RESPONSE SPECTRA ON SOIL VARIATION OF DAMPING	Figure 28
Woodward-Clyde Consultants			



Project No. 8830035B	INEL	PEAK ACCELERATION-ATTENUATION CURVE, M 6.9 INEL-1 AND ATR	Figure 29
Woodward-Clyde Consultants			



Project No. 8830095B	INEL	PEAK ACCELERATION-ATTENUATION CURVE, INEL-1 AND ATR	Figure 30
Woodward-Clyde Consultants			

END

DATE FILMED

5-6-94

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